



Morphological Evolution During Bulk GaN Growth

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A. Jaroszynska¹, K. Sierakowski¹, J.L. Weyher¹, L. Kirste³ and M. Bockowski¹

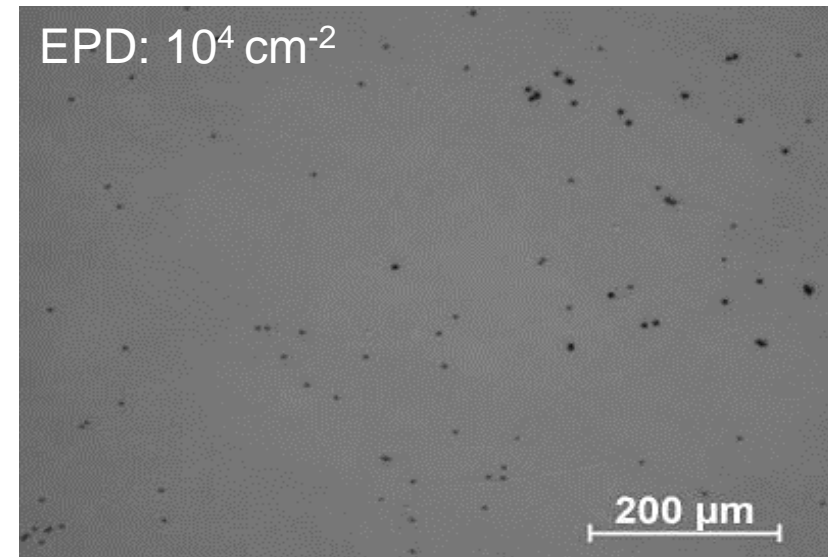
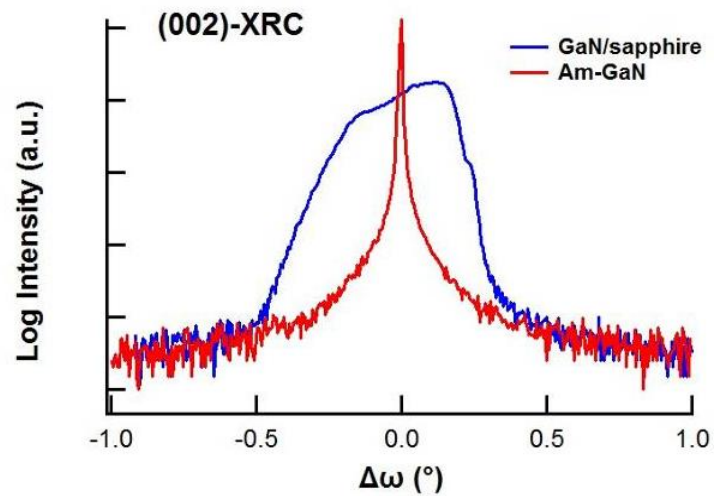
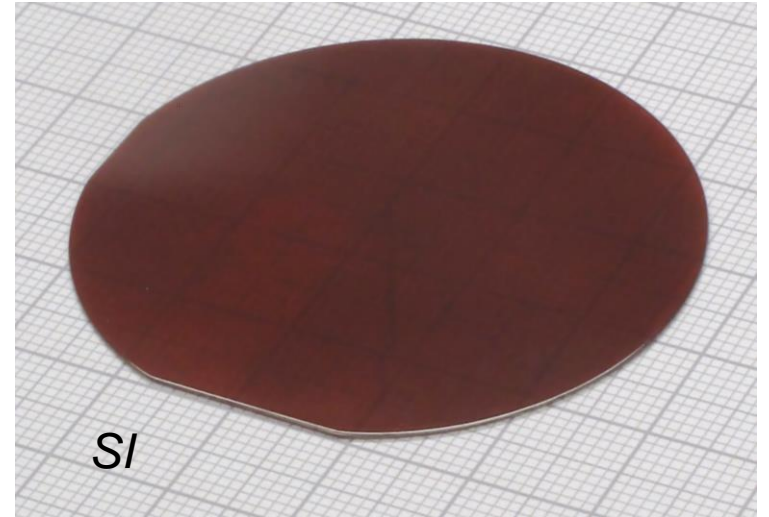
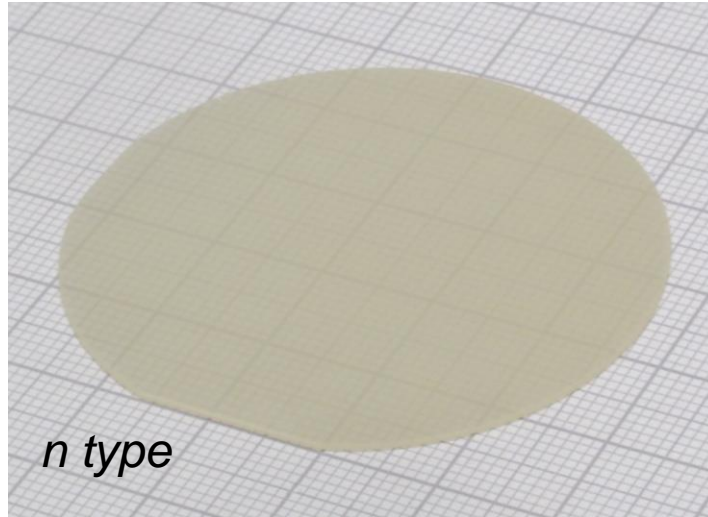
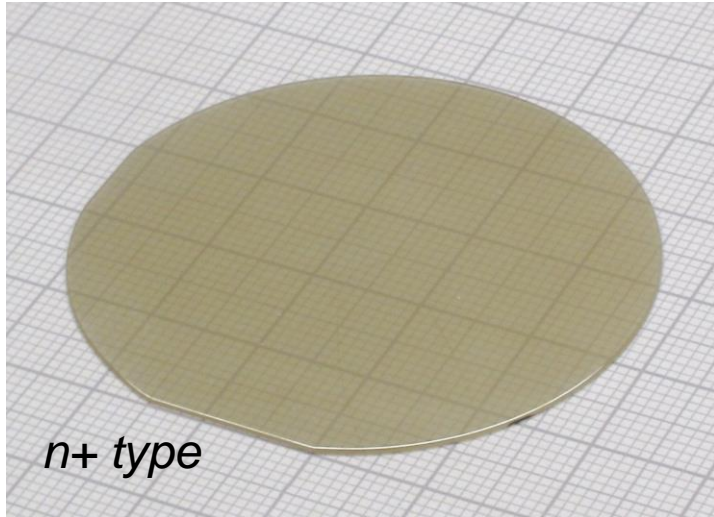
¹ Institute of High Pressure Physics Polish Academy of Sciences, Warsaw, Poland

² Laboratoire Charles Coulomb (L2C), University of Montpellier, CNRS, Montpellier, France

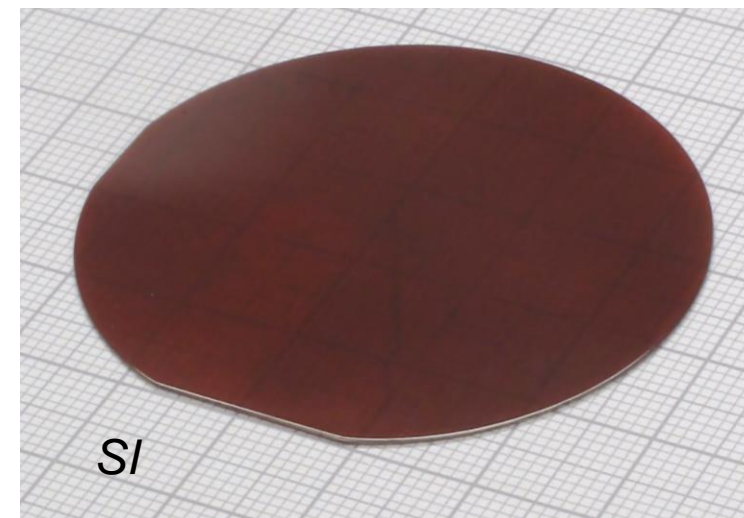
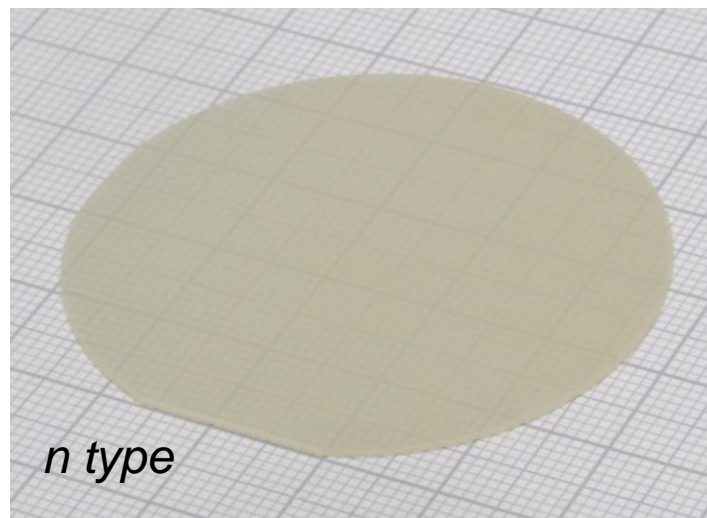
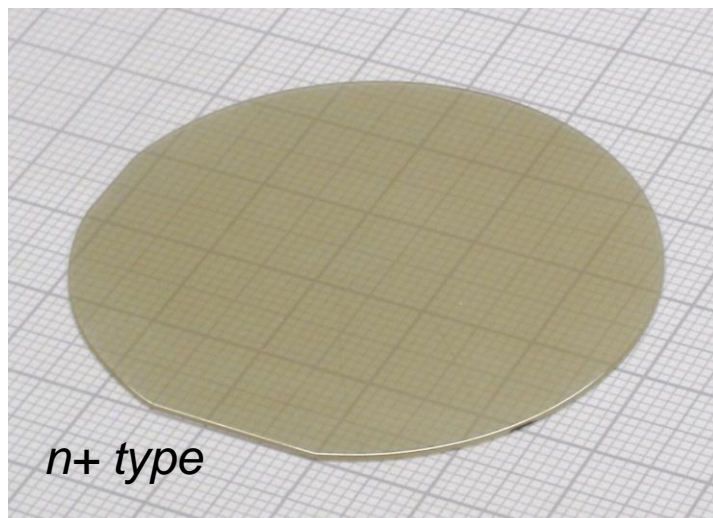
³ Fraunhofer Institute for Applied Solid State Physics (IAF), Freiburg, Germany

e-mail: tsochacki@unipress.waw.pl

2 inch Am-GaN substrates



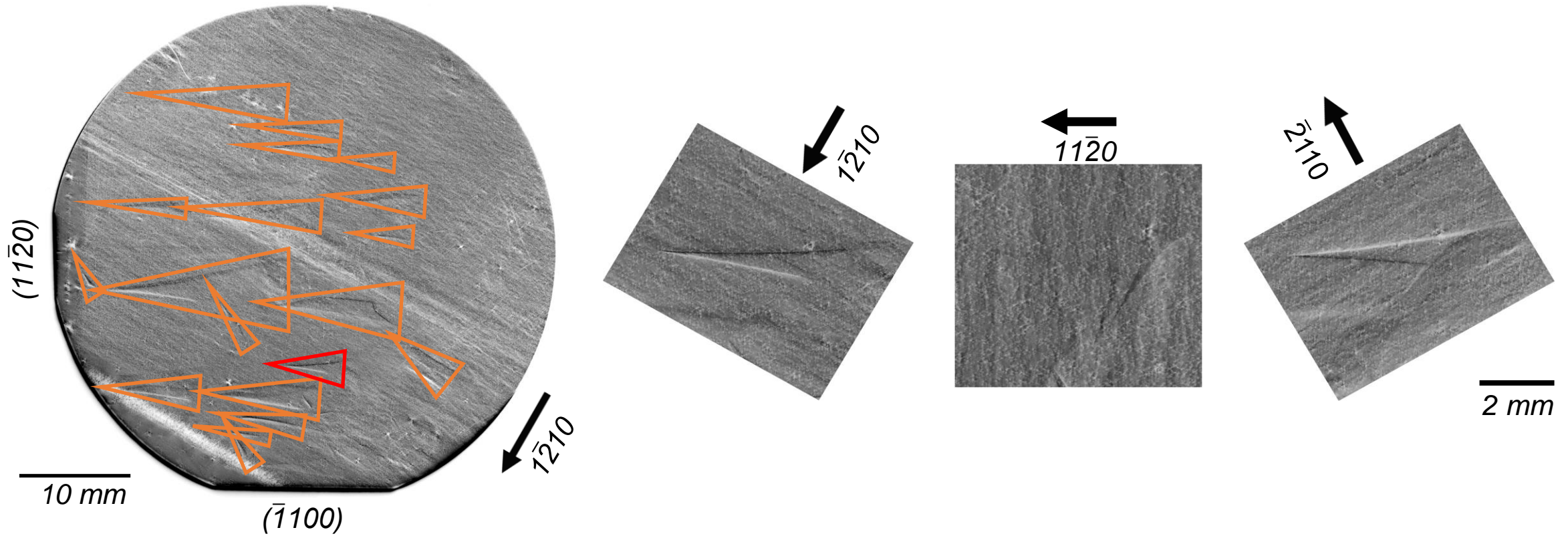
2 inch Am-GaN substrates – electrical properties



Material type	Conductivity type	Carrier concentration [cm ⁻³]	Carrier mobility [cm ² /Vs]	Resistivity [Ωcm]
High carrier concentration	n+ type	~10¹⁹	~150	10 ⁻³
Low carrier concentration	n type	~10¹⁸	~250	10 ⁻²
High resistivity (Mn-doped)	semi-insulating (SI)	-	-	≥10⁸

Uniformity of electrical properties.

Triangular areas – structural inhomogeneities

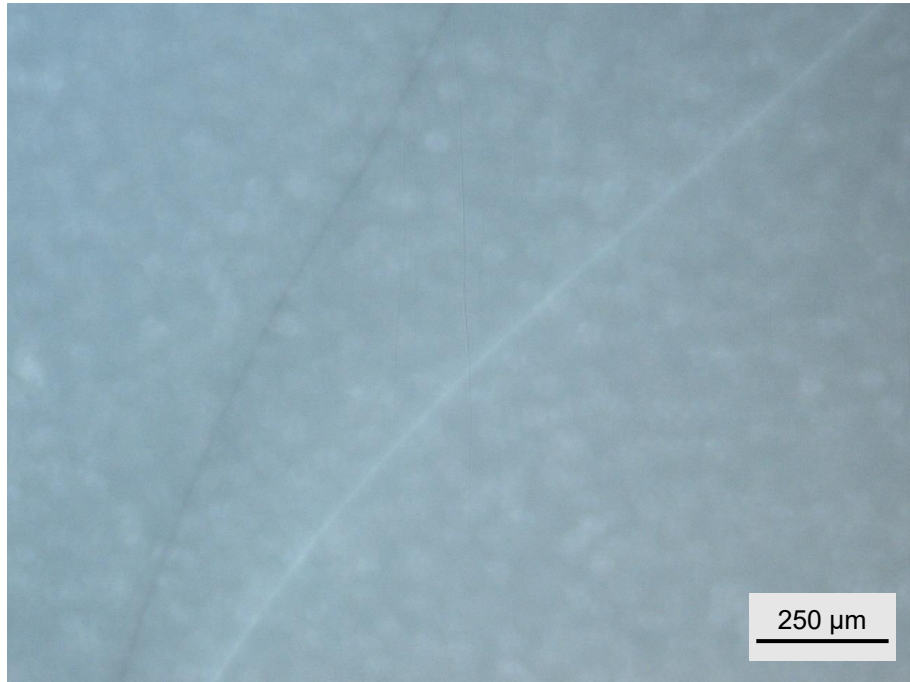


XRT of Am-GaN substrate –
Borrmann effect

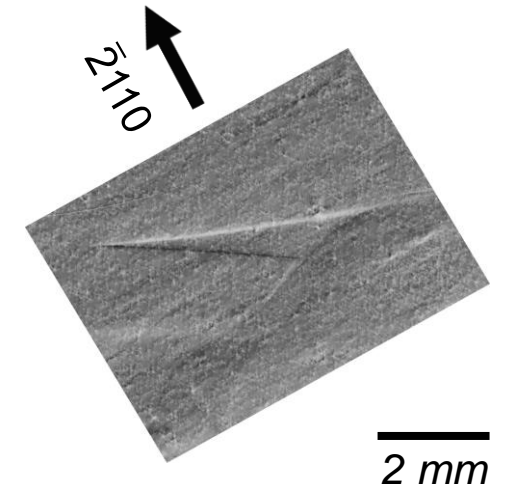
L. Kirste et al., Materials 2021, 14, 5472.

Triangular areas – structural inhomogeneities

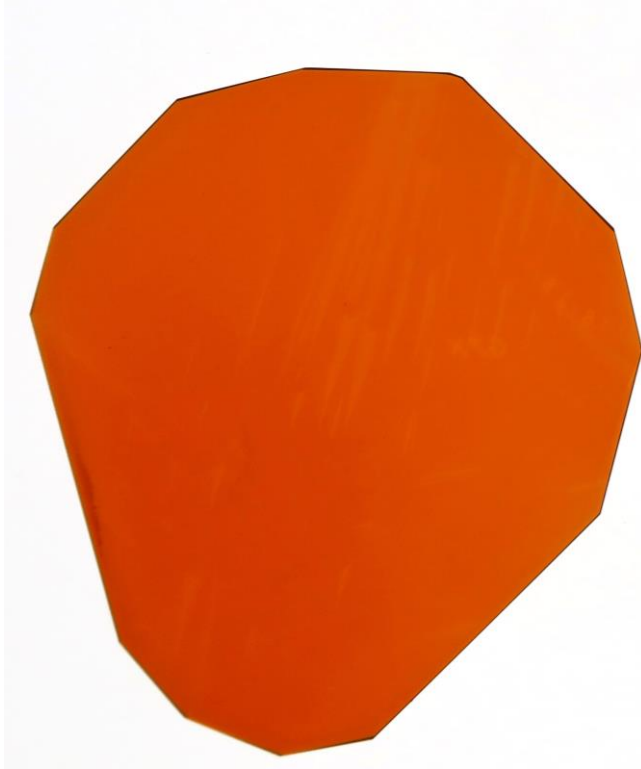
n+-type Am-GaN after CMP



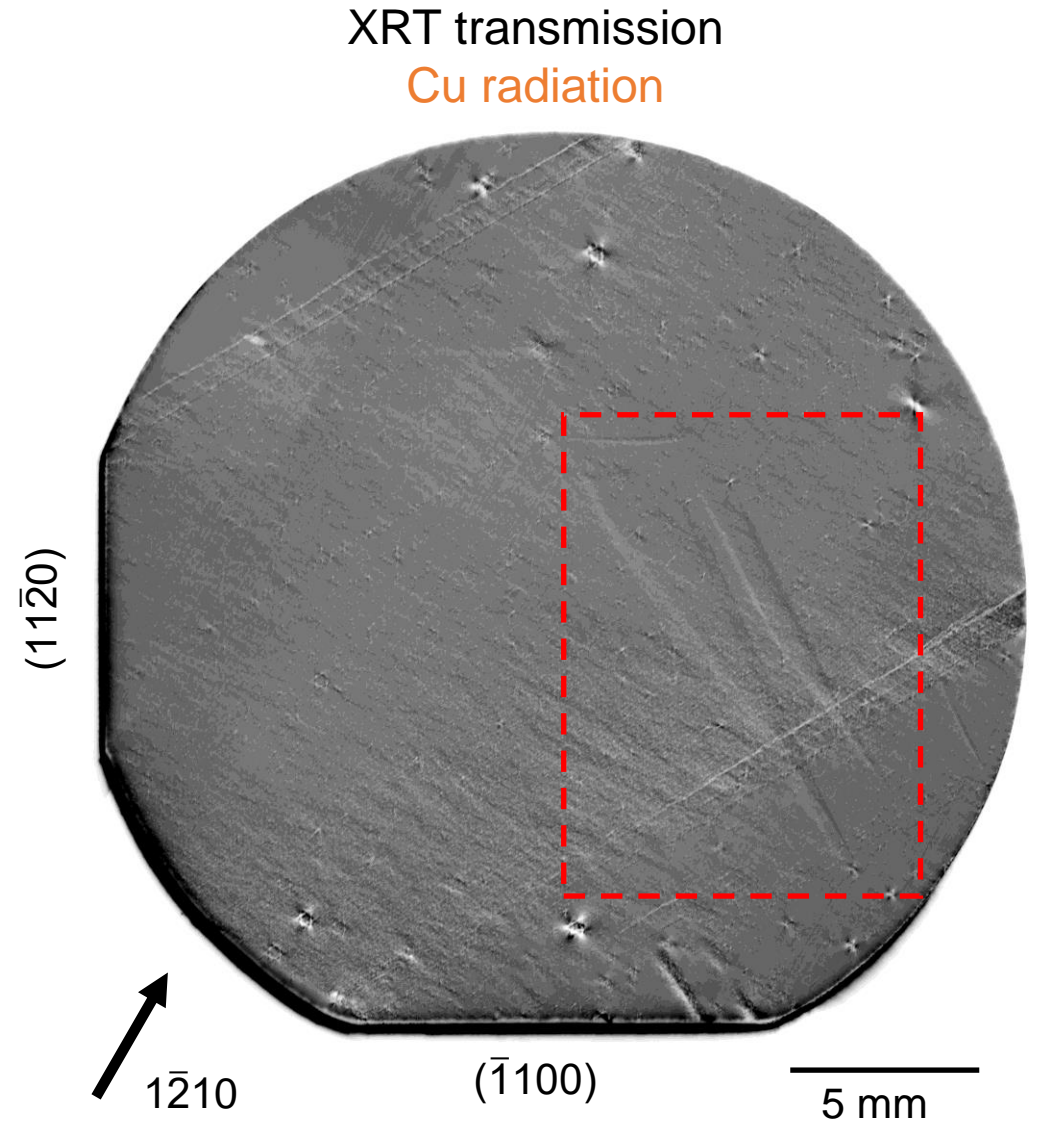
OM under UV light - n-type Am-GaN



Triangular areas – structural inhomogeneities

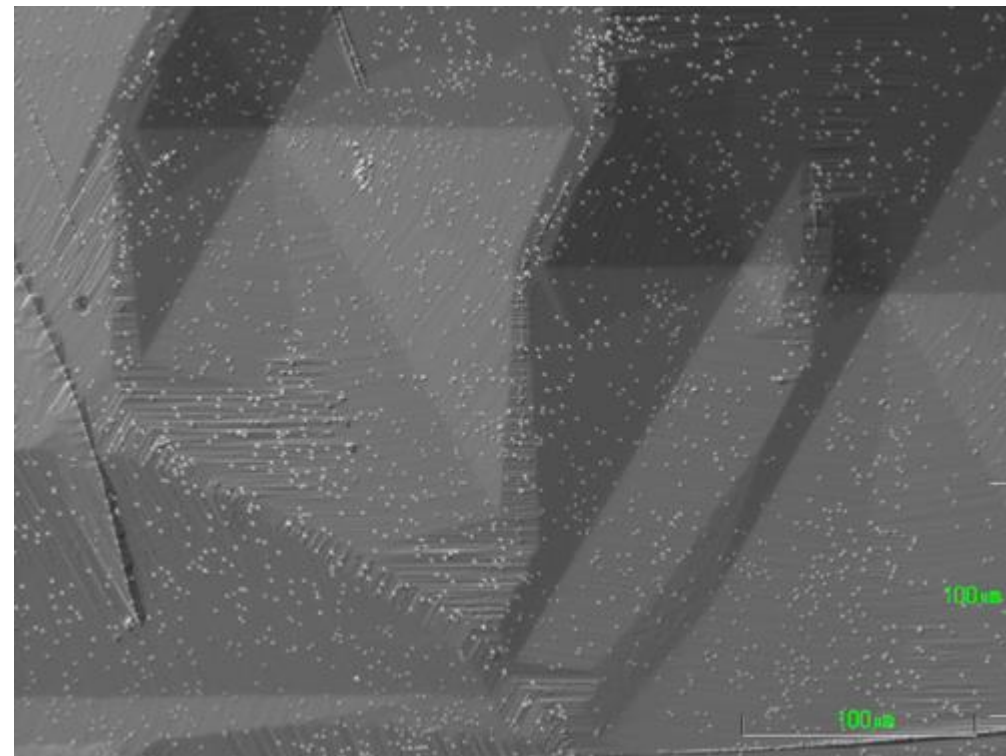
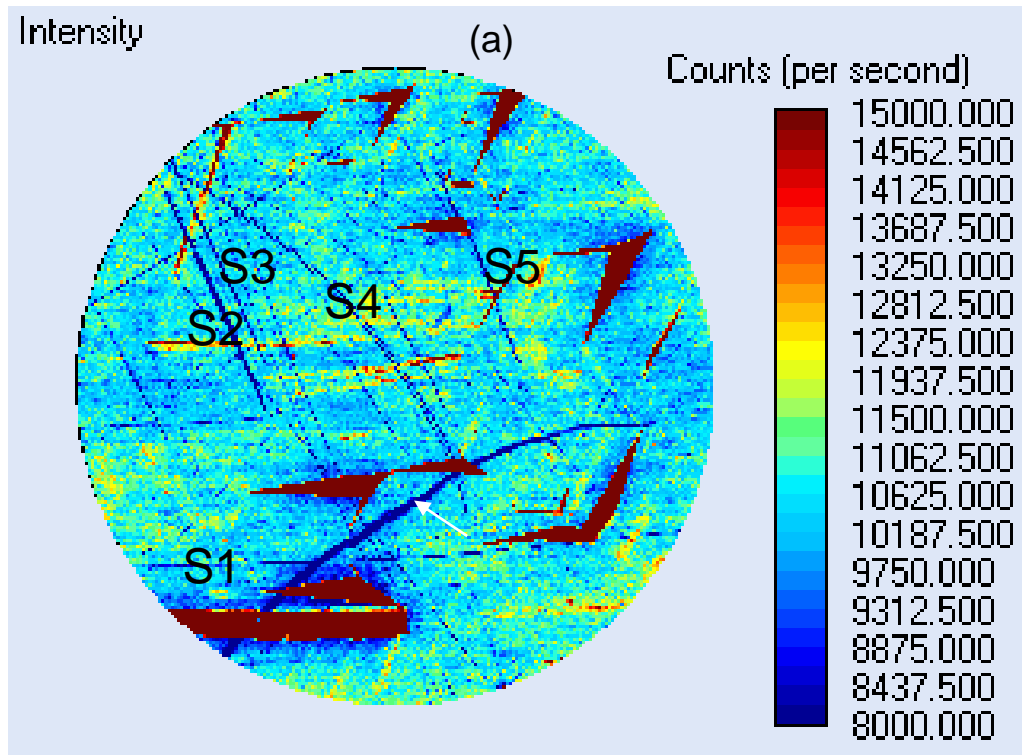


SI Am-GaN (VIS light)



HR PL mapping

Report – Analysis of GaN samples

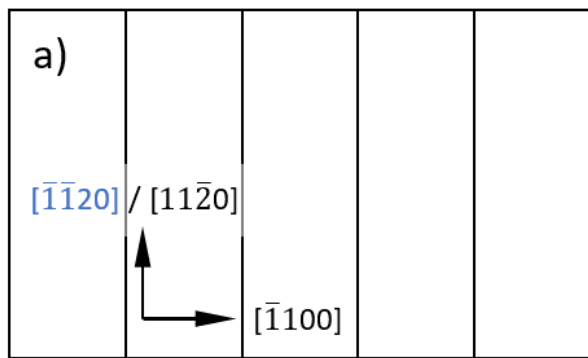


J.L. Weyher

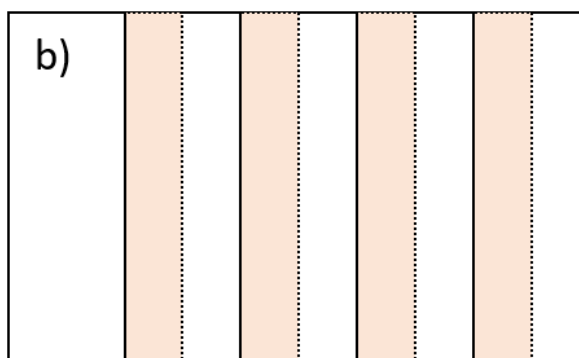
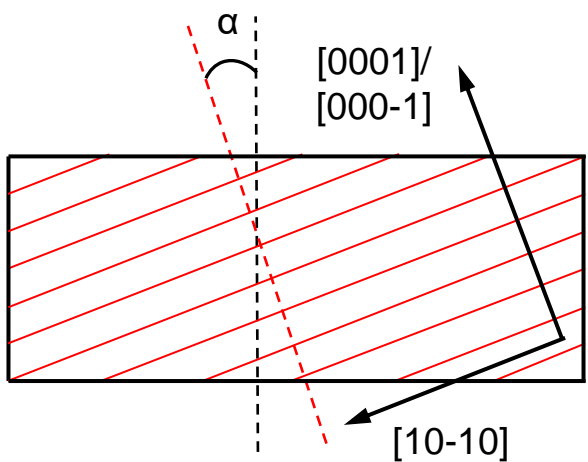
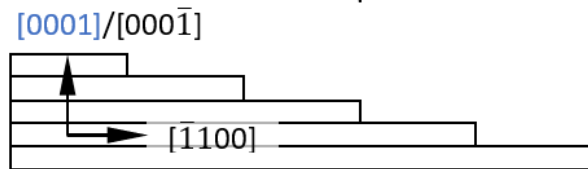
Radboud University Nijmegen, IMM, Applied Materials Science – Nijmegen, The Netherlands
 Institute of High Pressure Physics, Polish Academy of Sciences – Warsaw, Poland

The presence of these inhomogeneities is related to the growth mode of the crystal used for fabrication of the substrate.

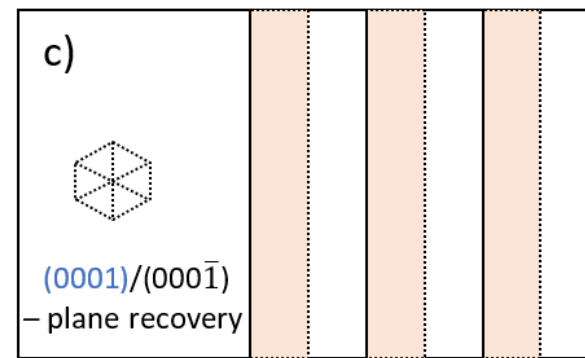
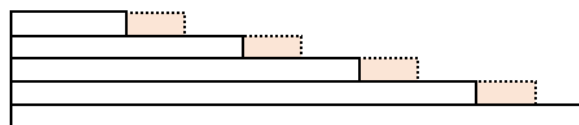
Growth model of the bulk GaN



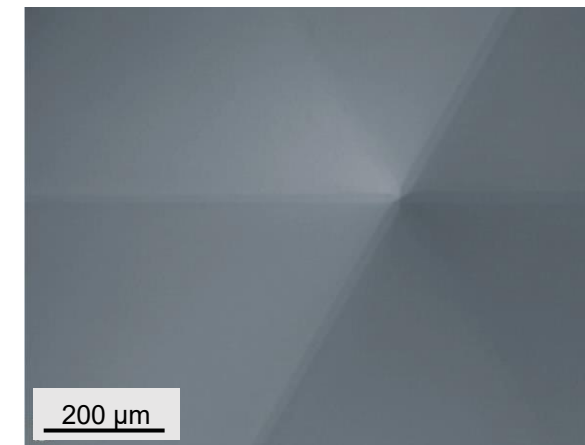
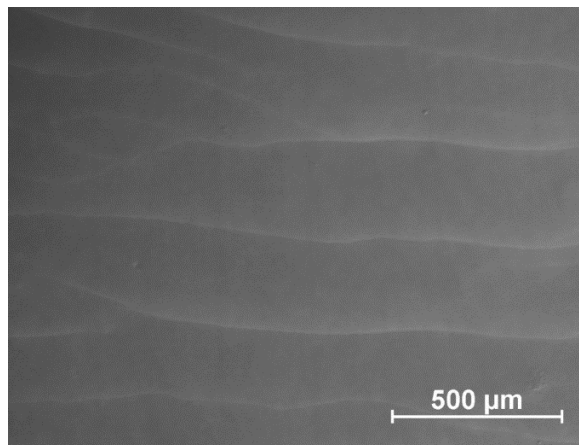
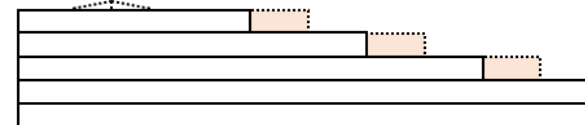
Atomic steps



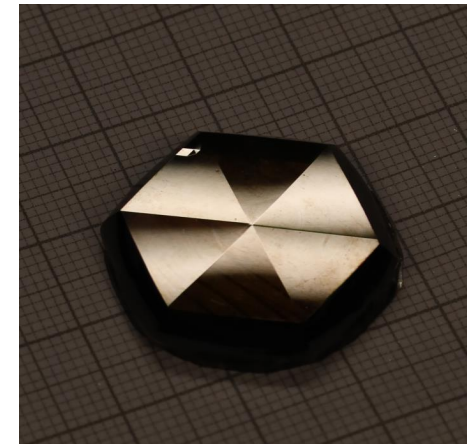
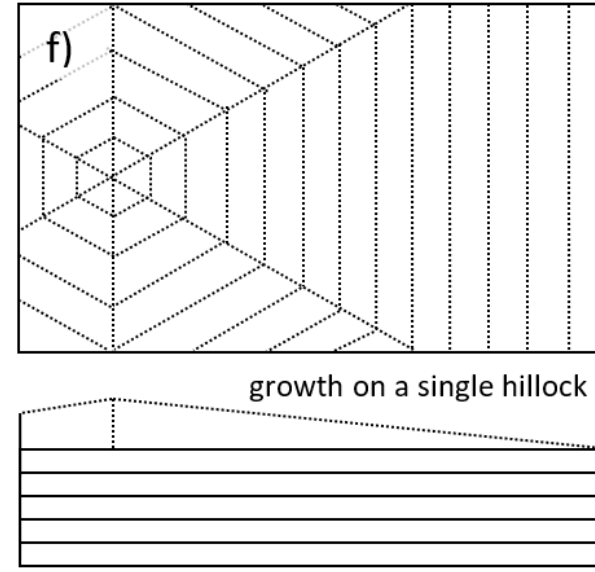
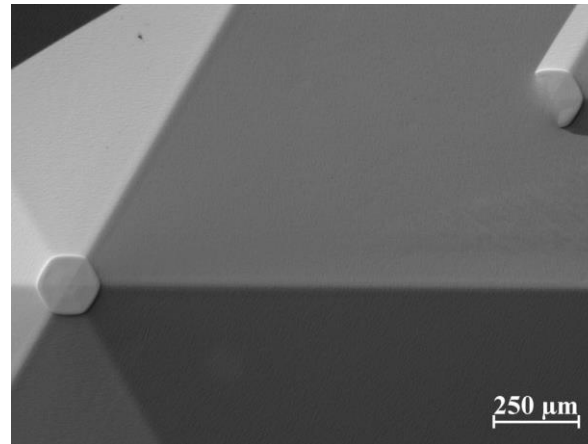
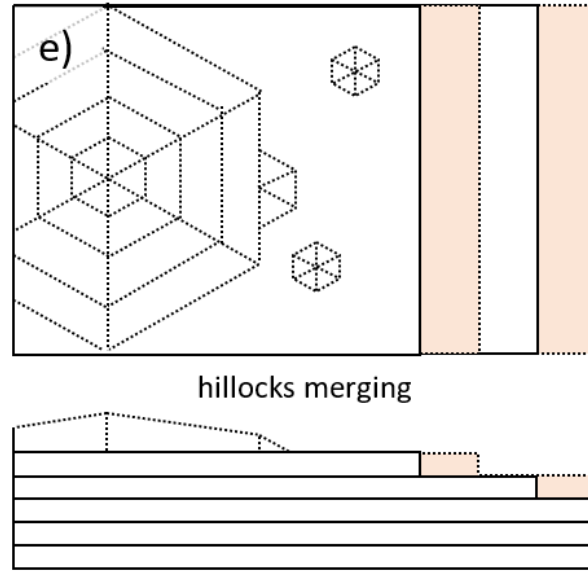
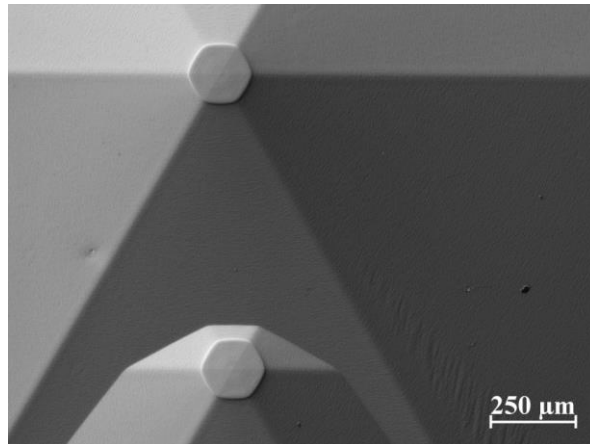
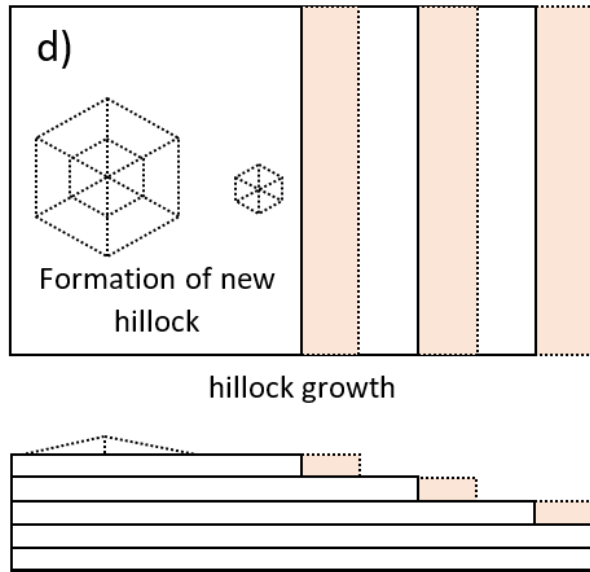
Step propagation



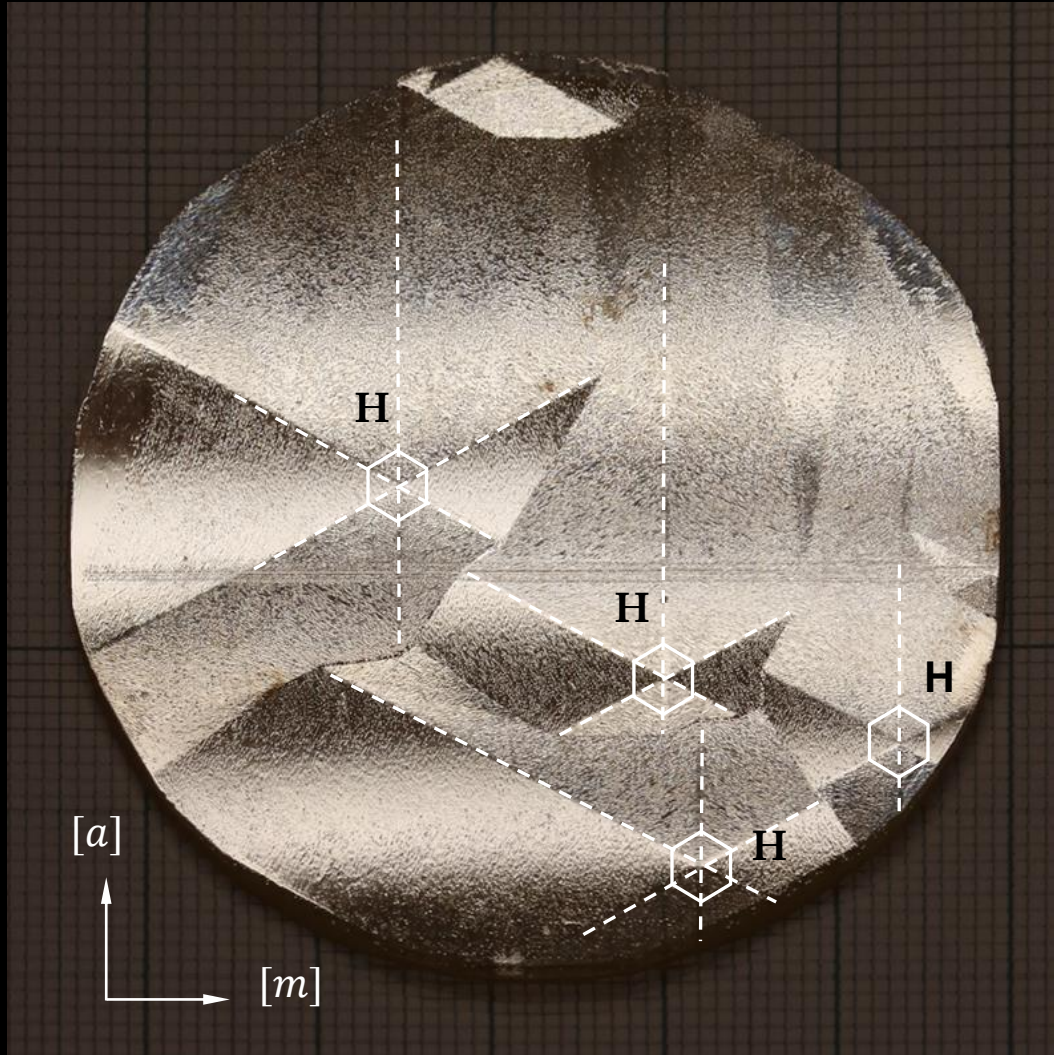
Hillock formation



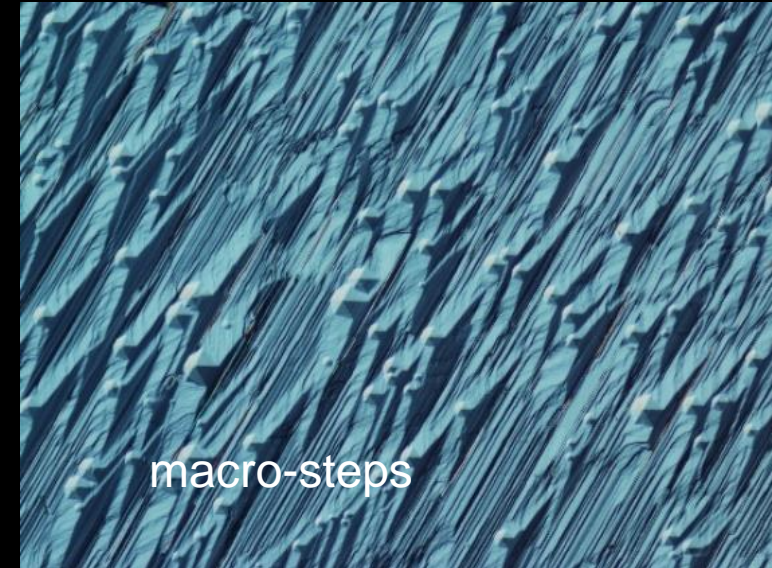
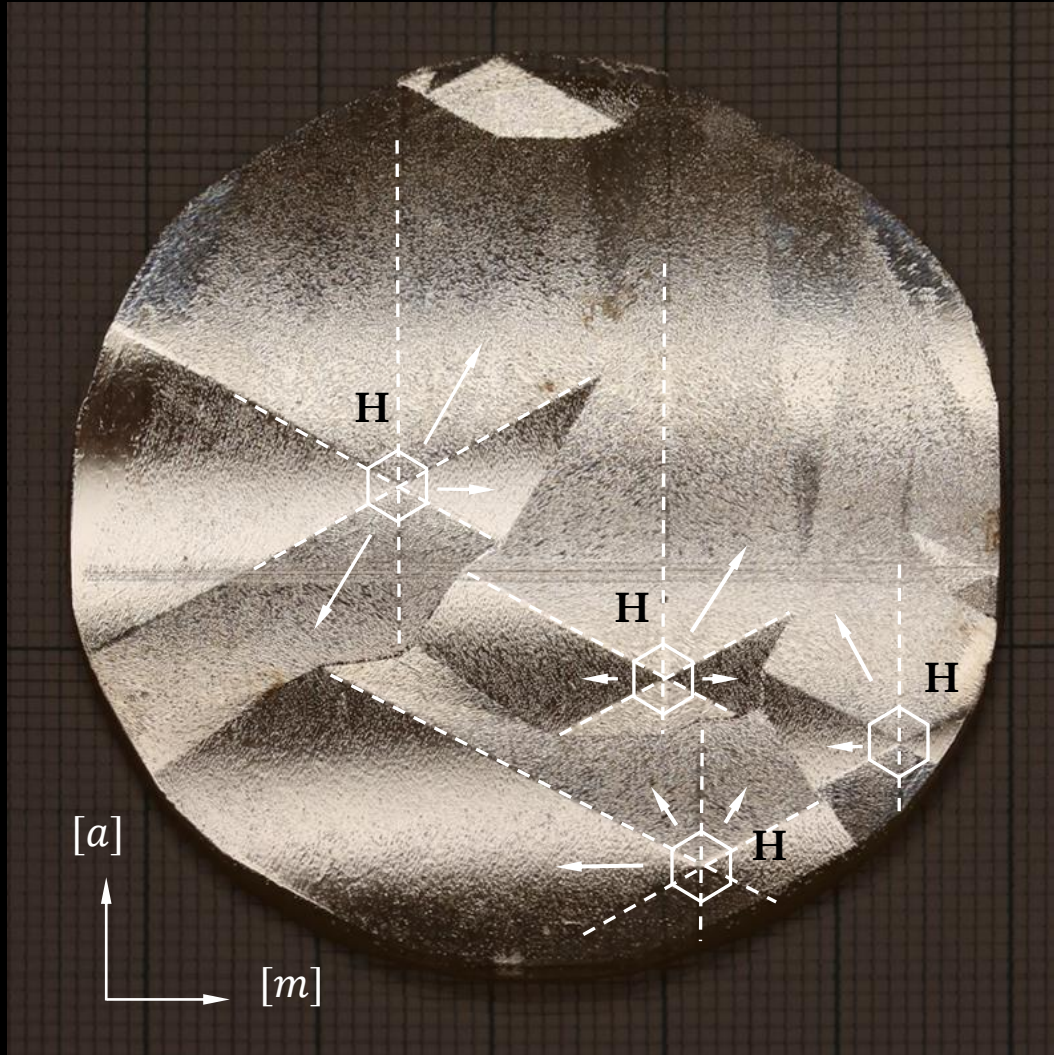
Growth model



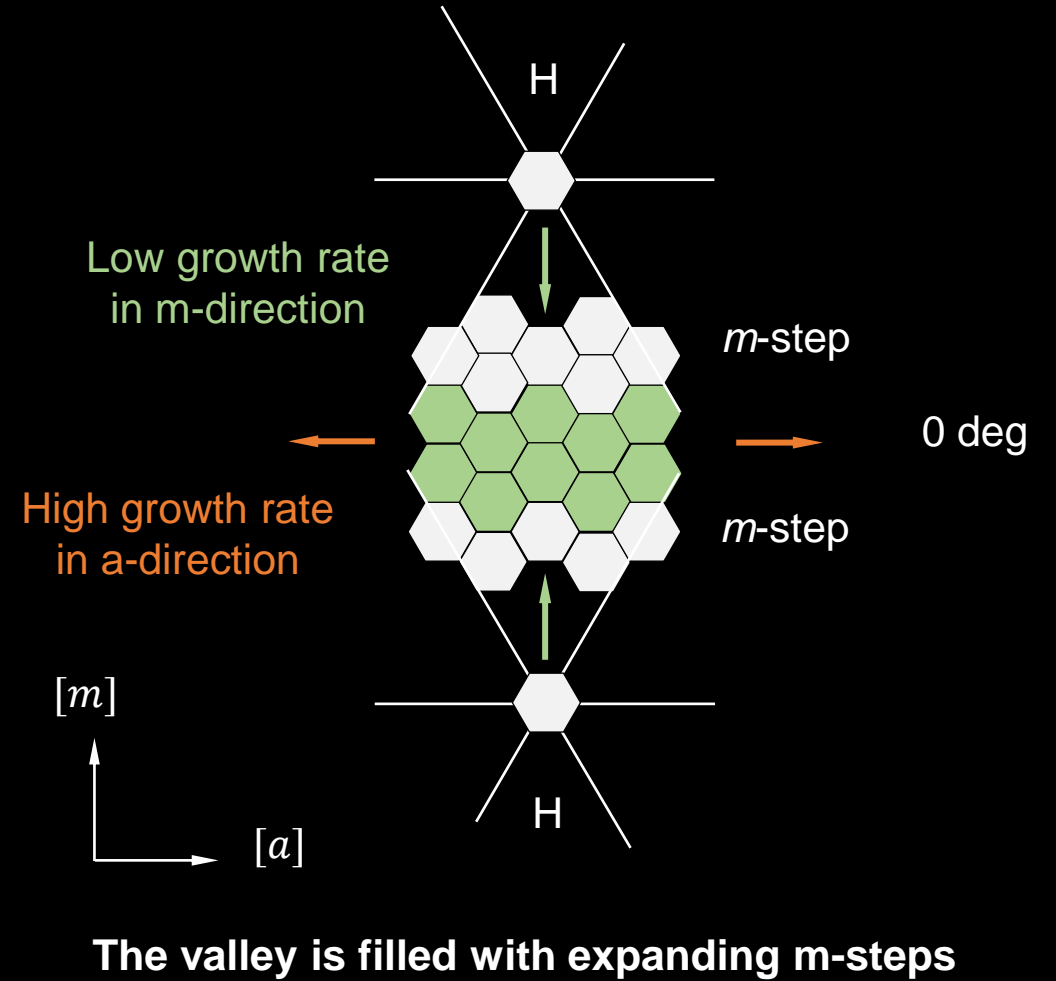
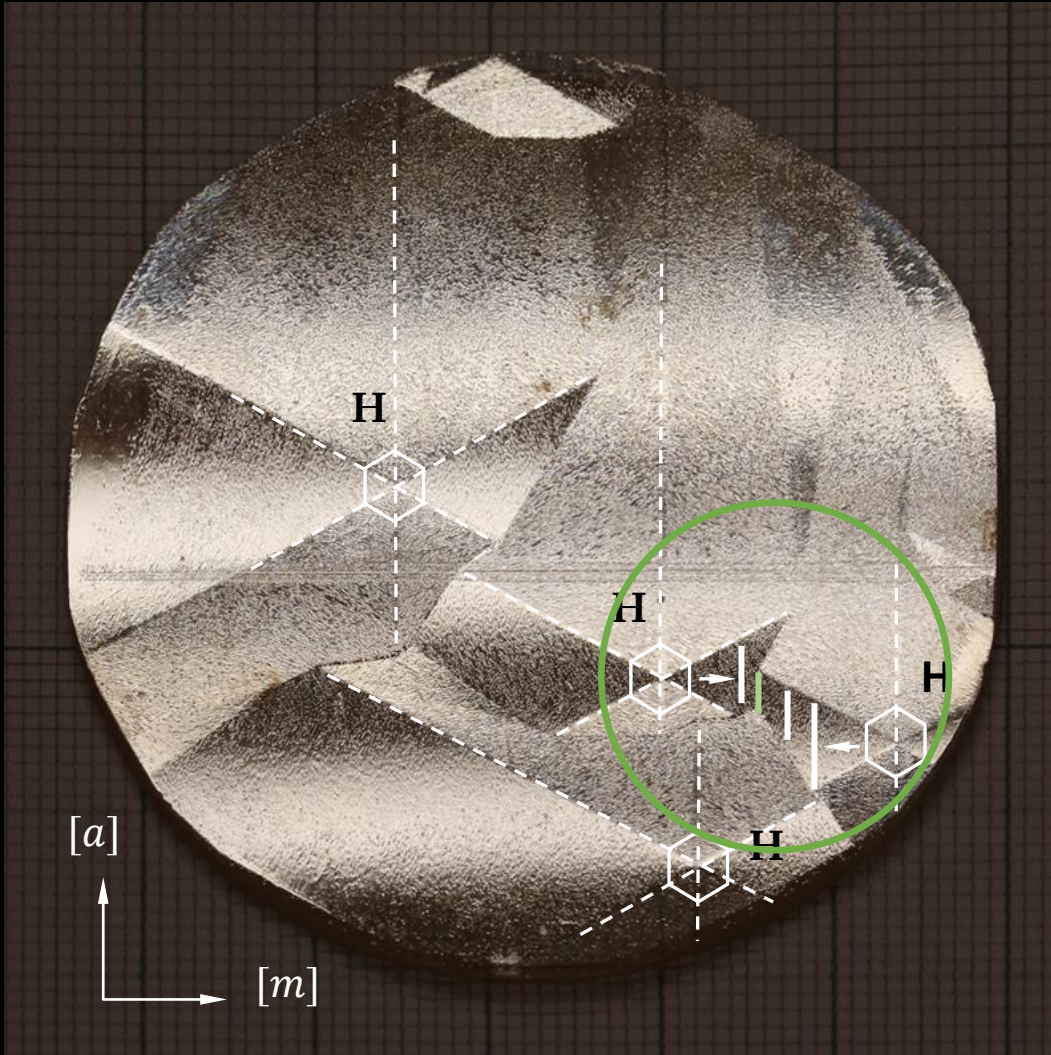
As-grown n-type Am-GaN crystal



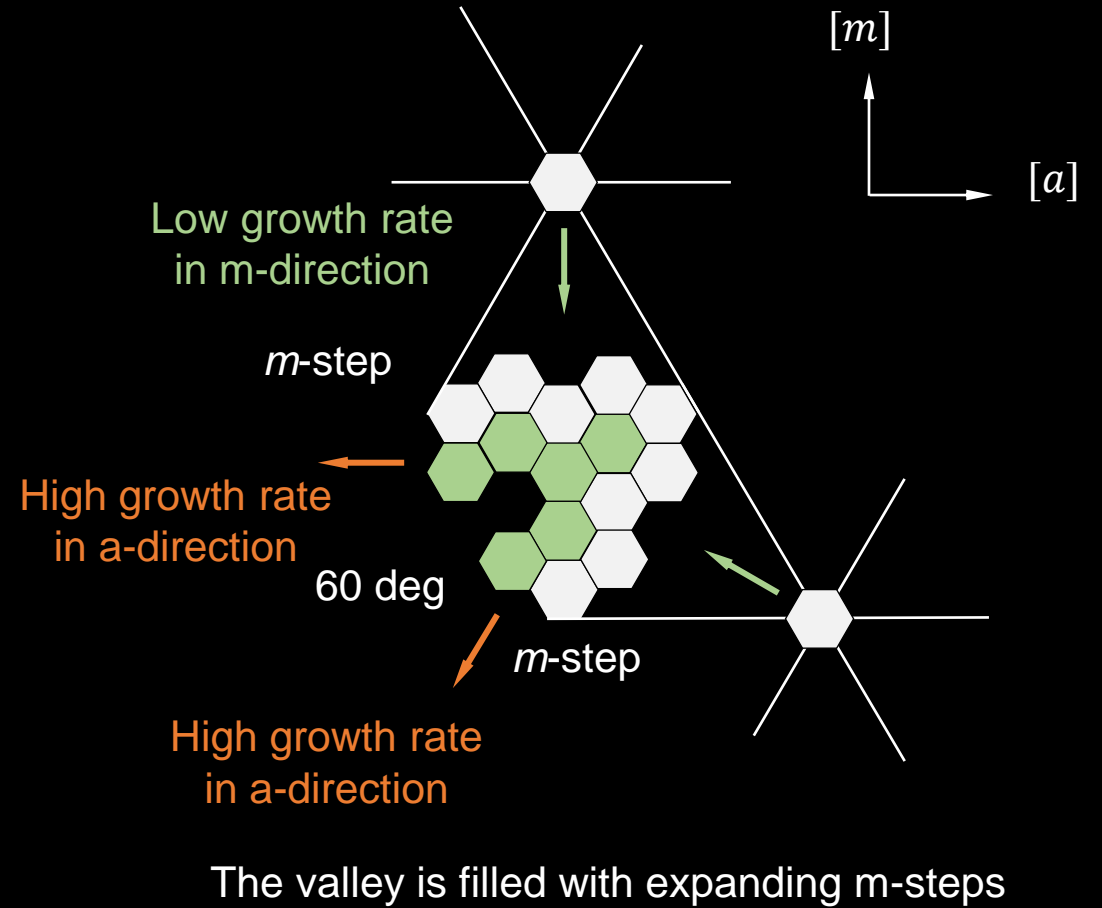
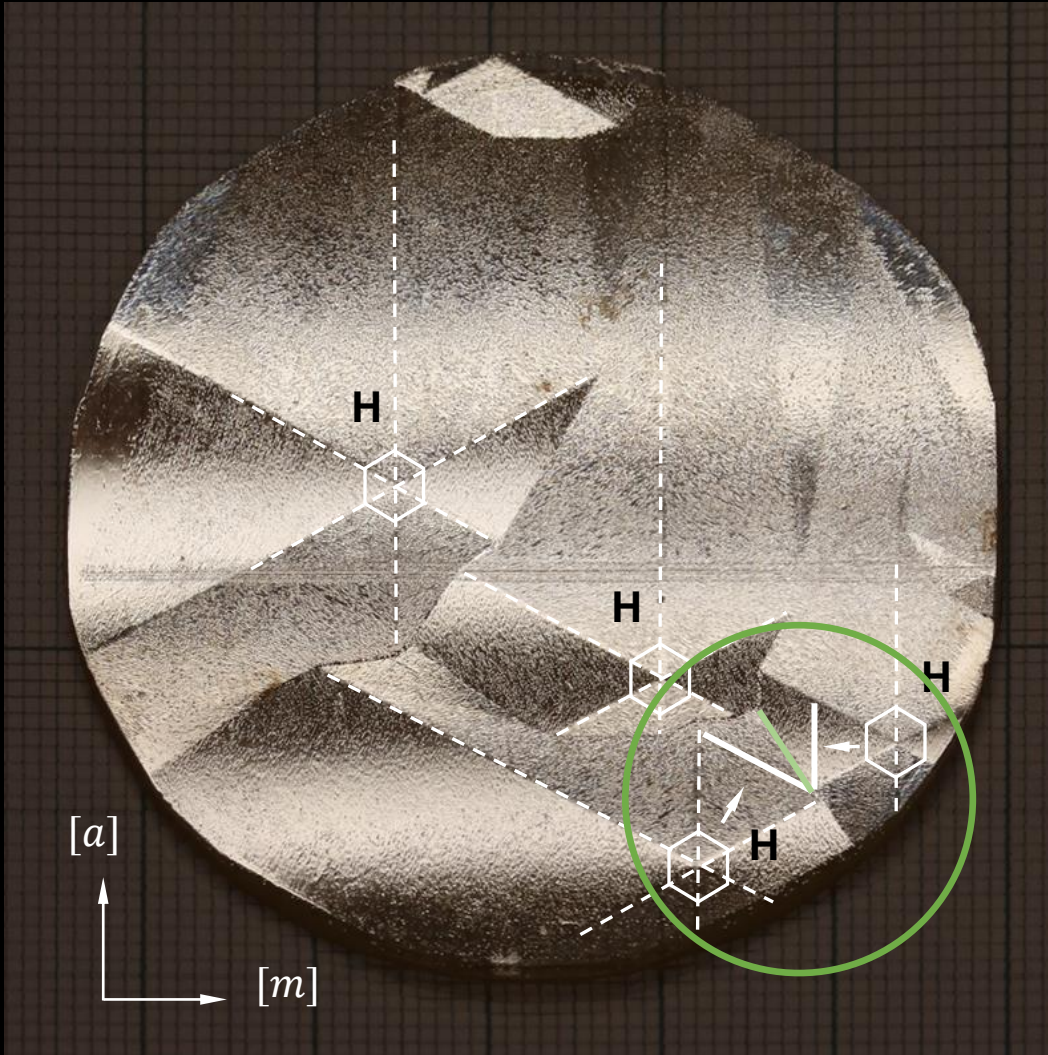
Analysis of the growth morphology



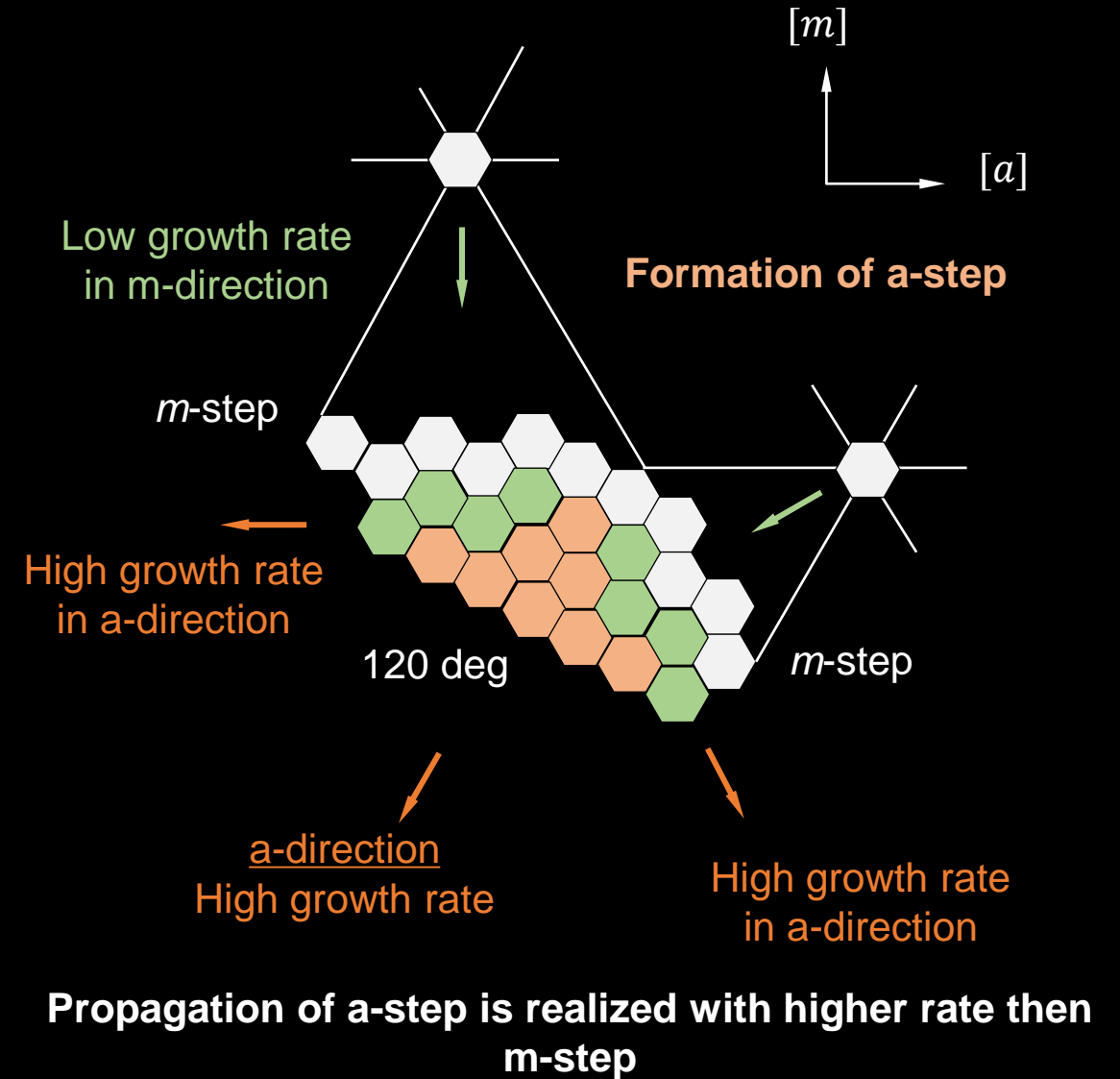
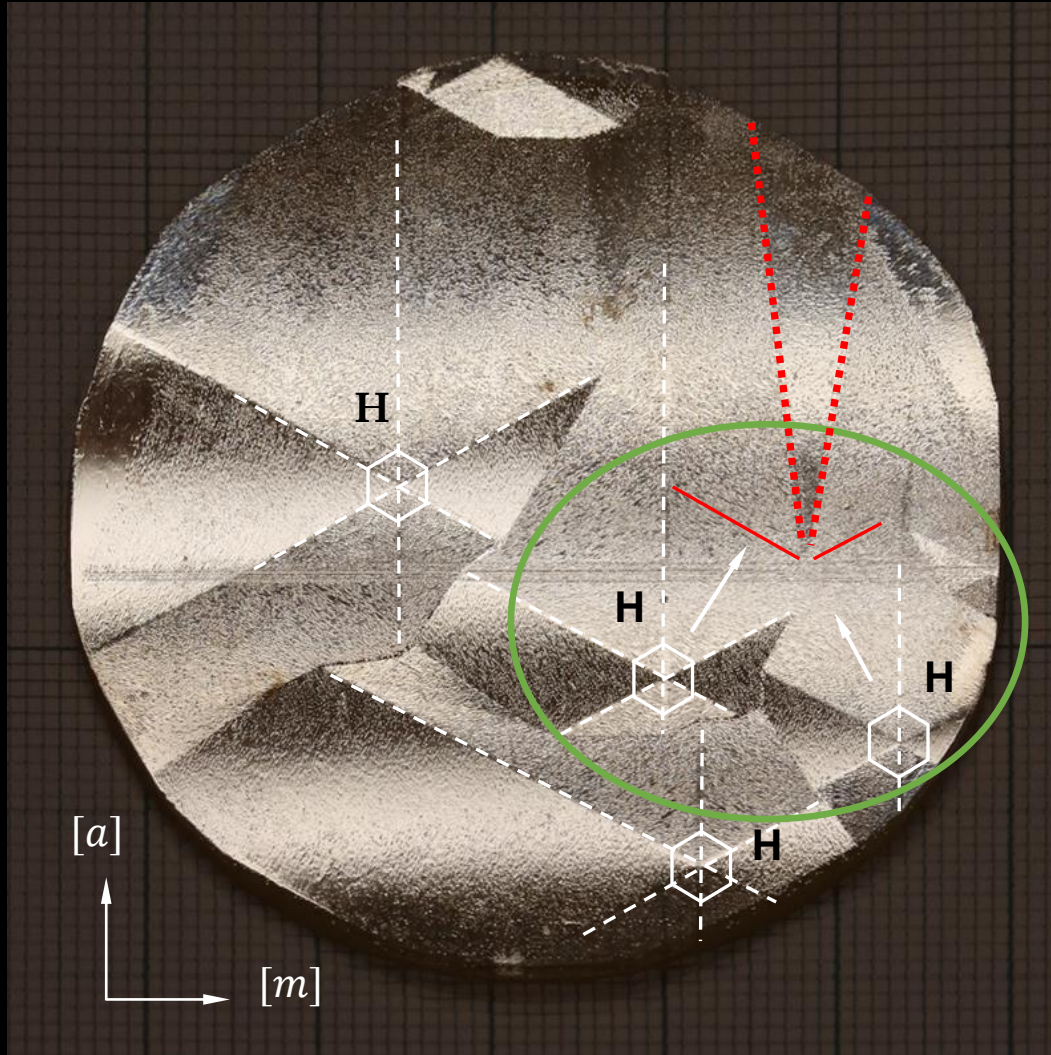
0 deg between steps on adjacent hillocks



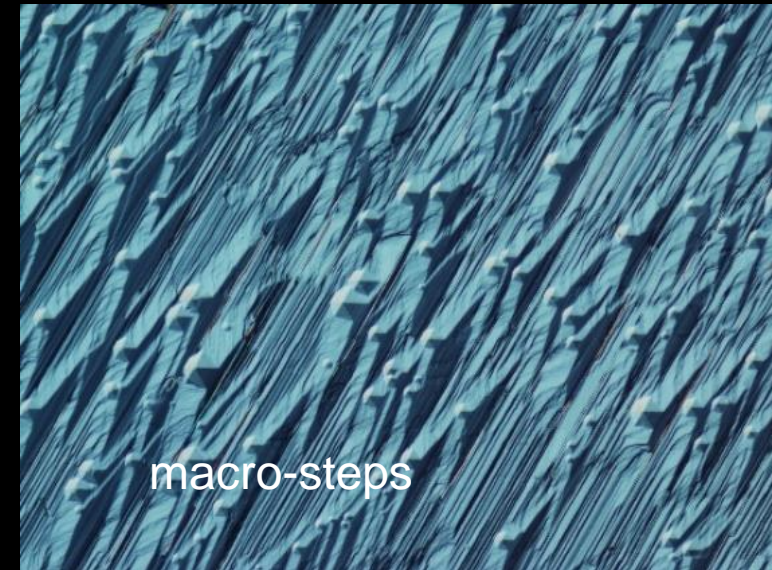
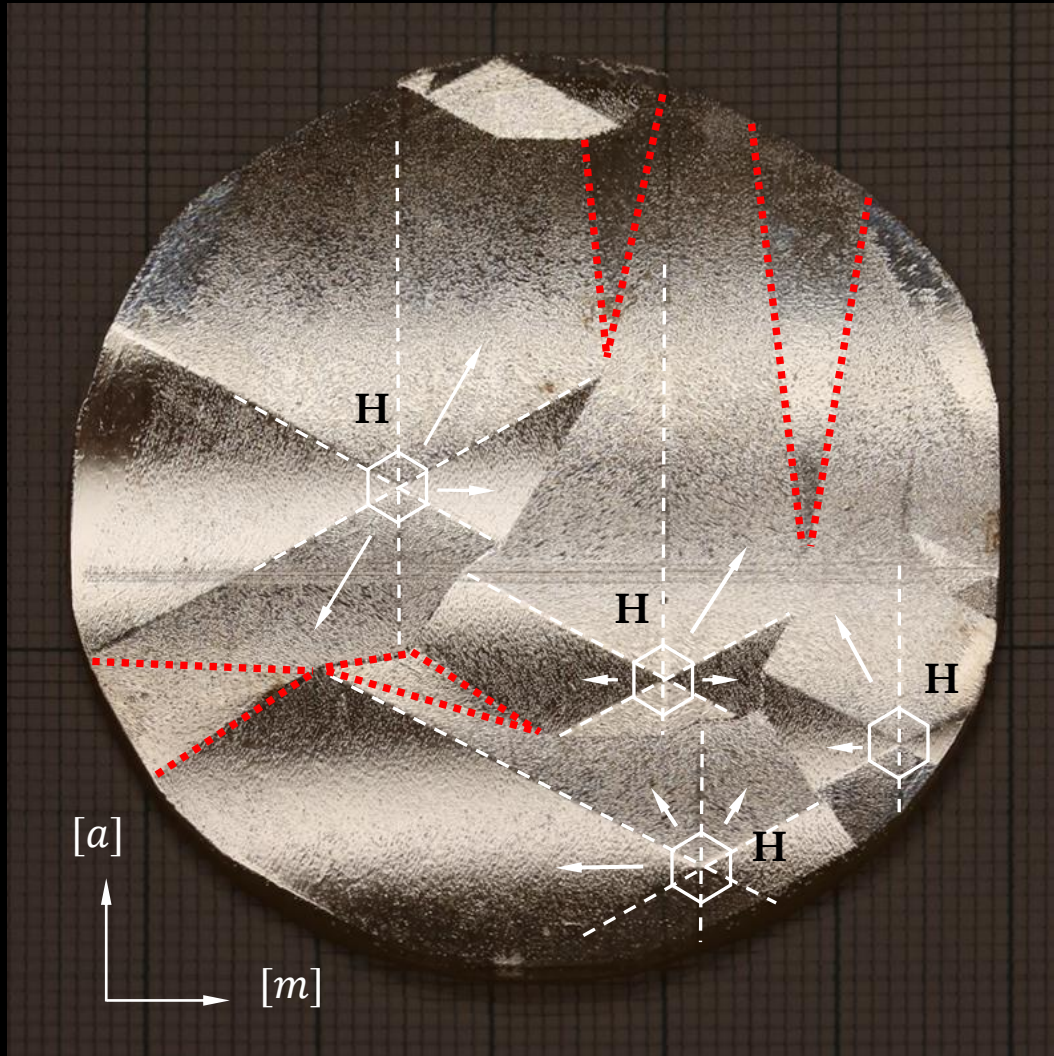
60 deg between steps on adjacent hillocks



120 deg between steps on adjacent hillocks

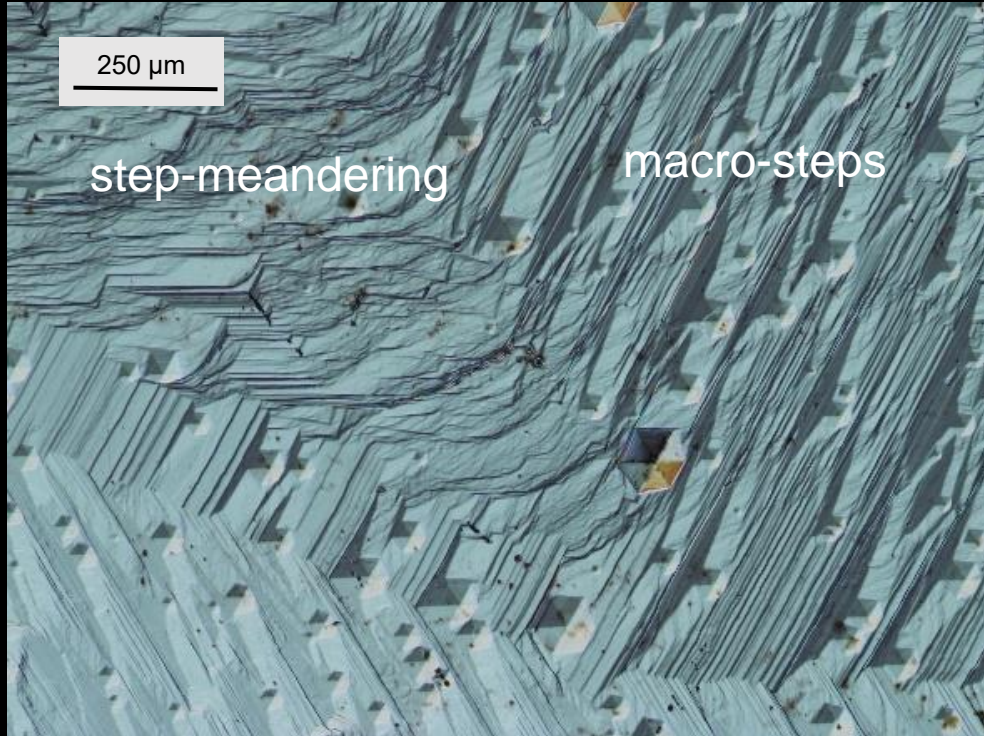


Analysis of the growth morphology

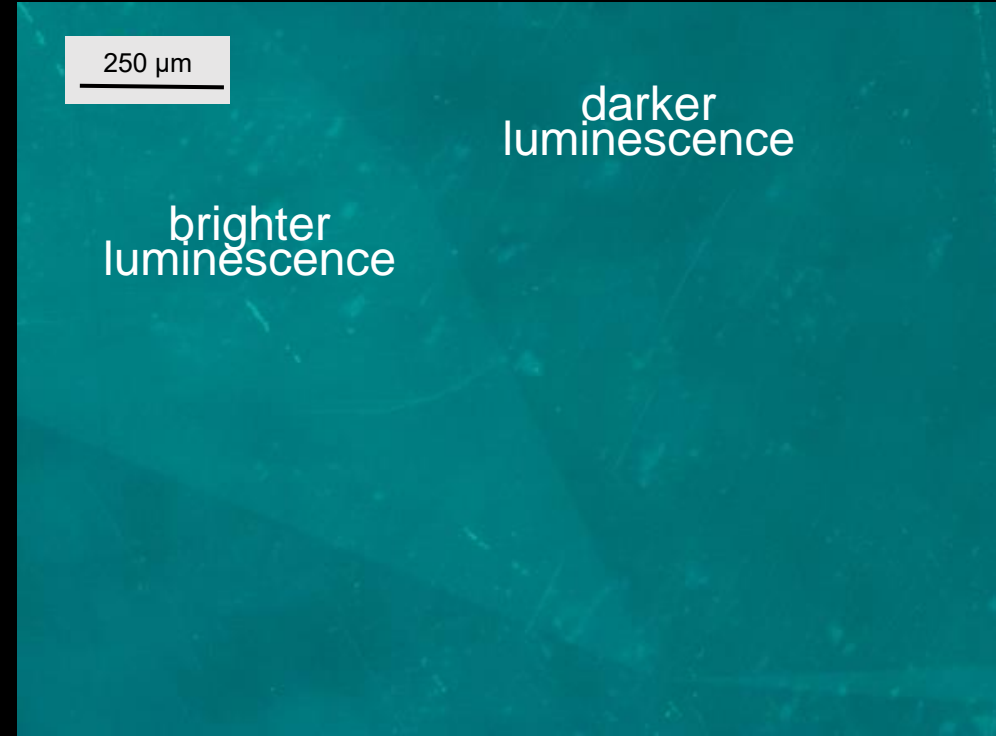


Analysis of the growth morphology

Nomarski contrast



UV illumination

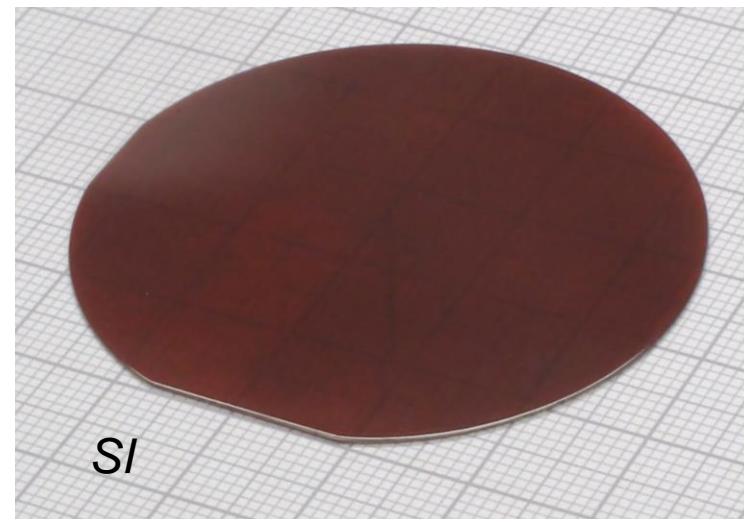
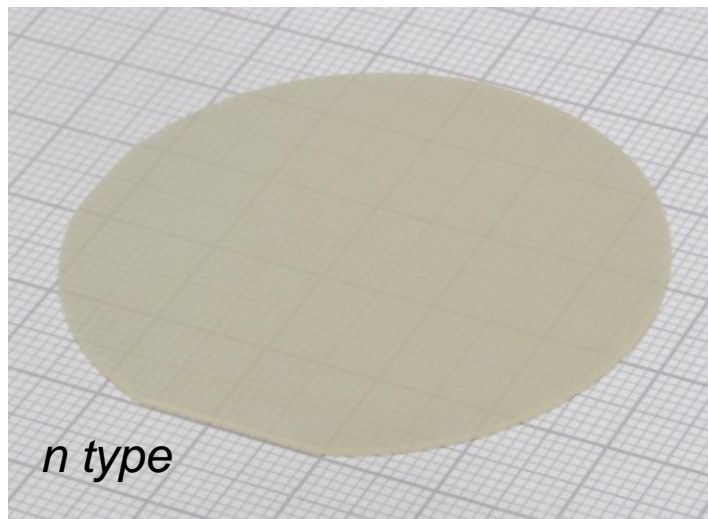
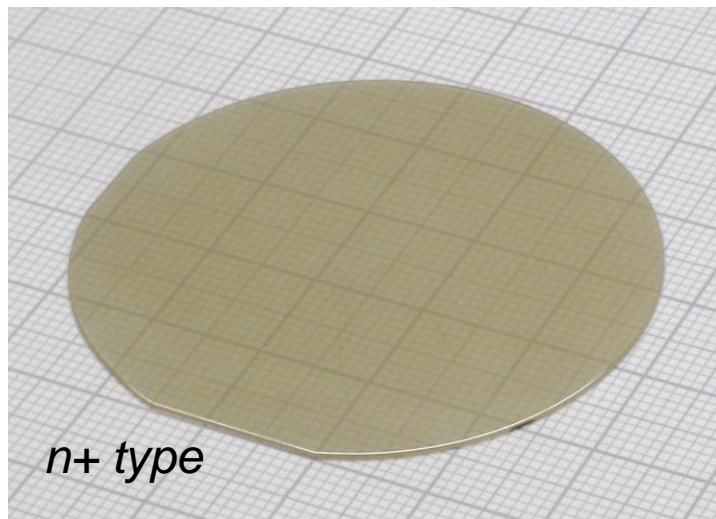


The places where the **macro-steps** are visible correspond to an area of **darker luminescence**.
 In turn, areas with **step-meandering** correspond to parts with **brighter luminescence**.

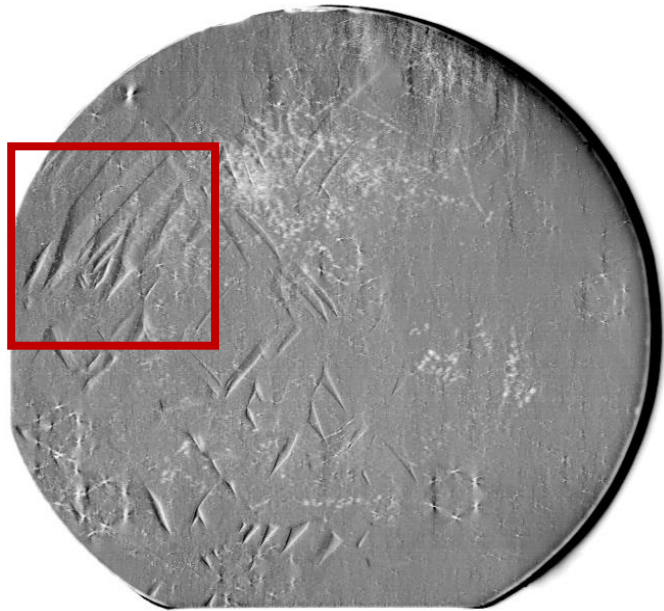
n+ vs n type

Am-GaN

2 inch Am-GaN substrates – electrical properties



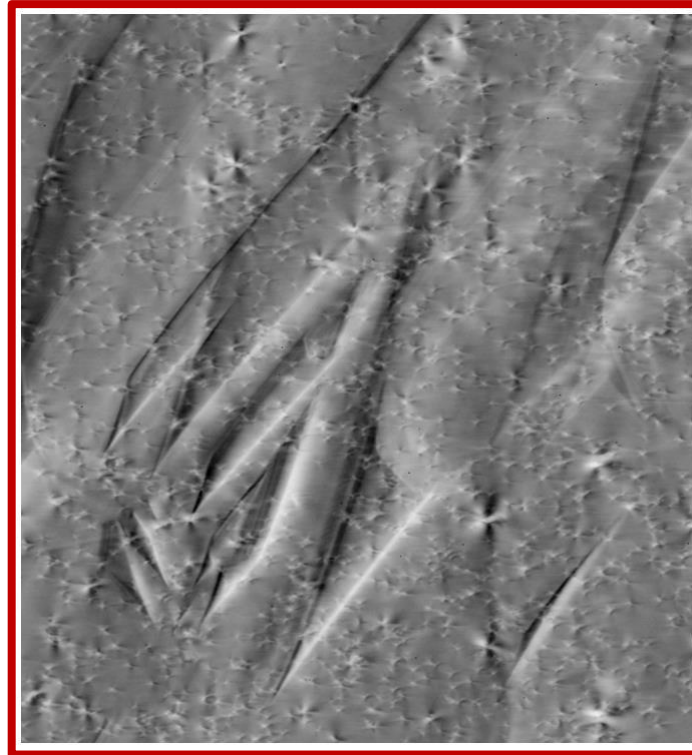
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5 mm

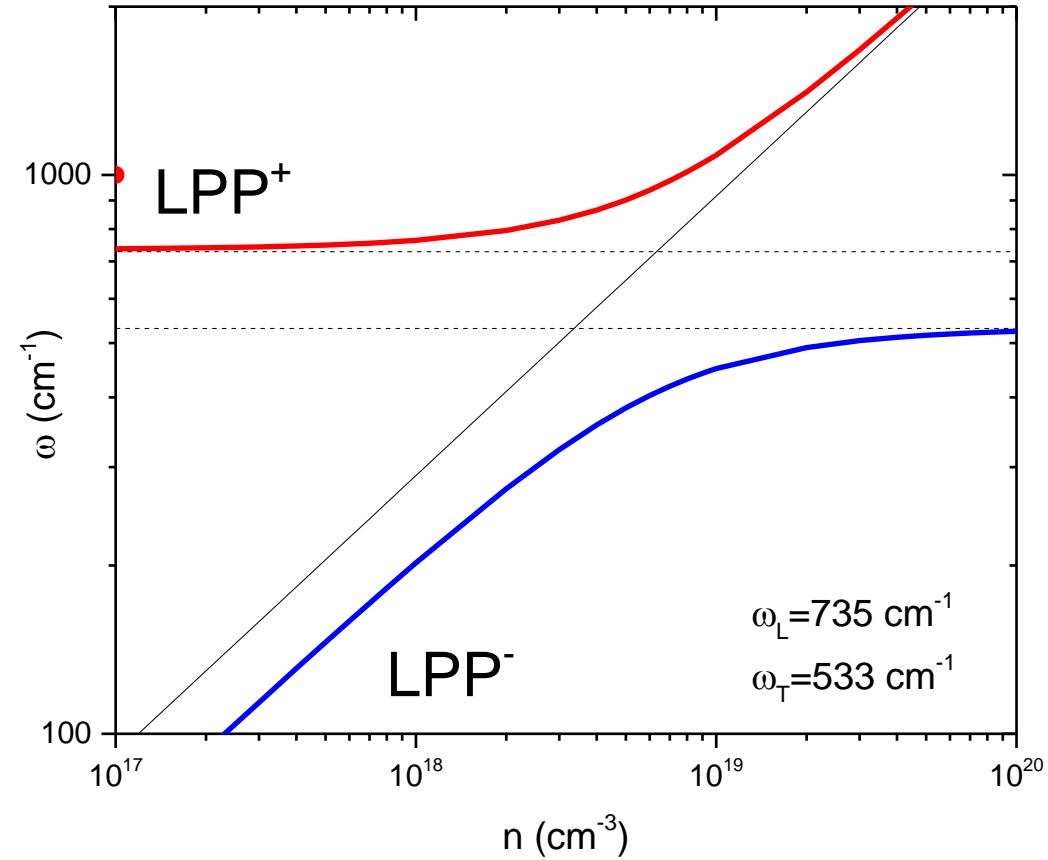
→
11 $\bar{2}$ 0

XRT of Am-GaN substrate –
Borrmann effect



OM (UV)

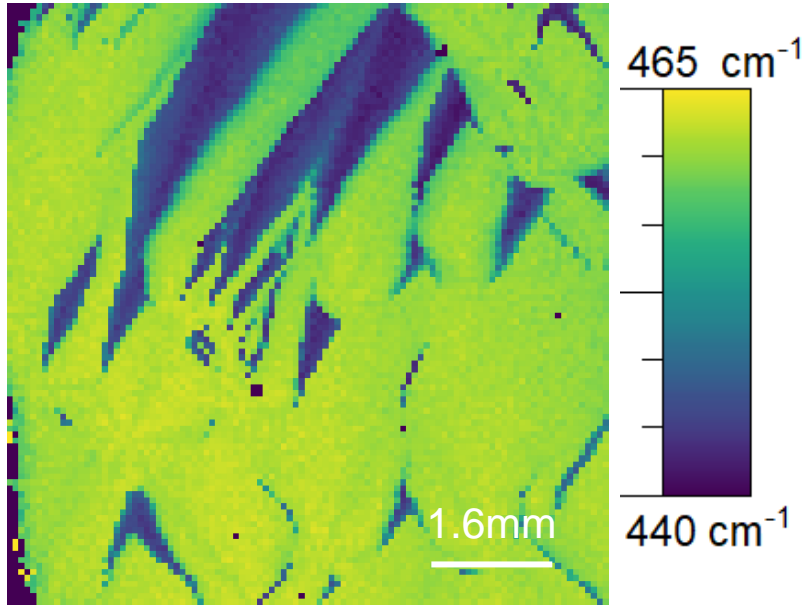




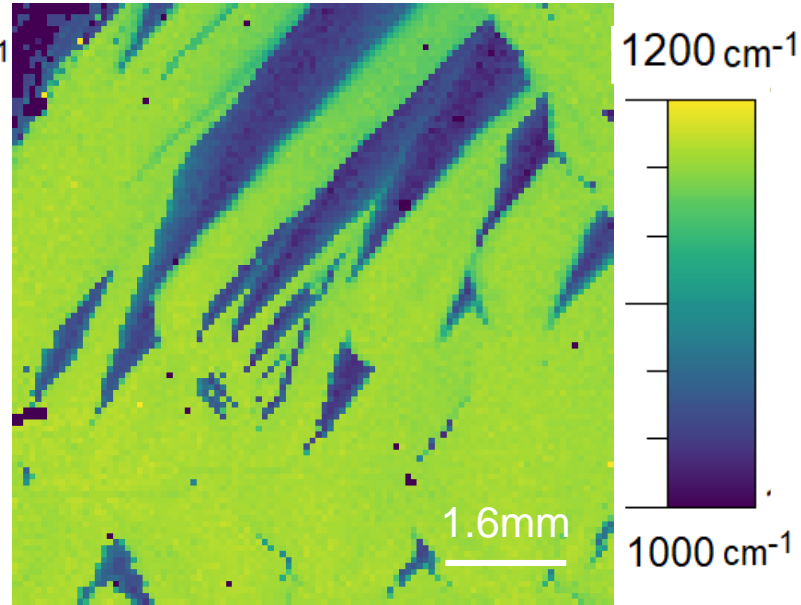
Harima et al J. Phys. : Condensed Matter 14 R967 (2002)

LPP- , LPP+ Raman signature

Raman shift LPP-



Raman shift LPP+



OM (UV)

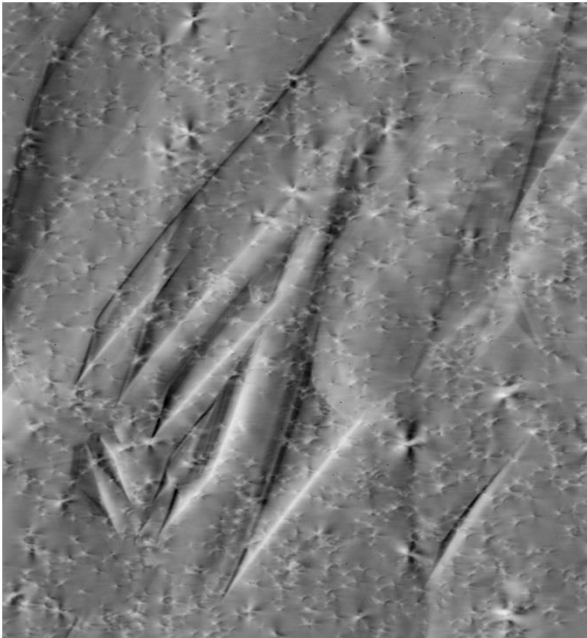


n+ Am-GaN

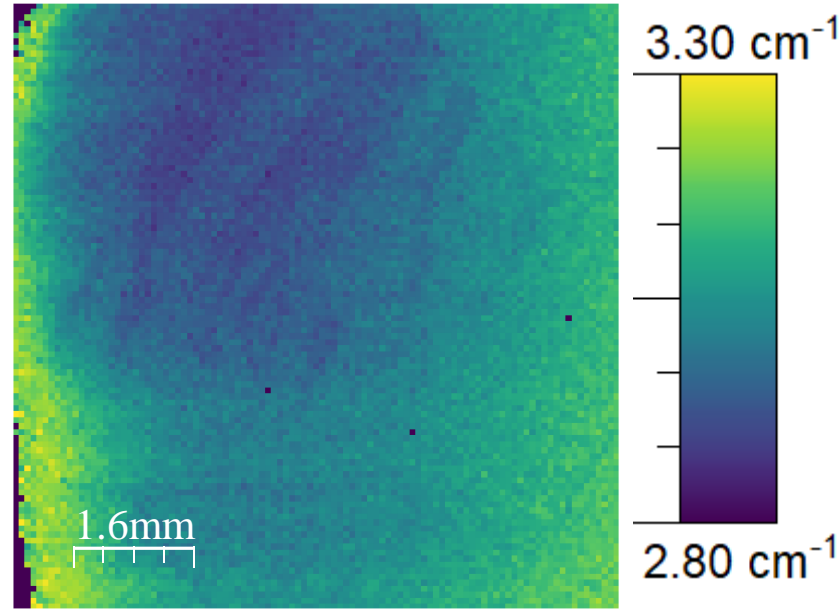
The area inside of "propellers" region is characterized by a lower free carriers concentration.

E₂ Raman signature vs XRT transmission

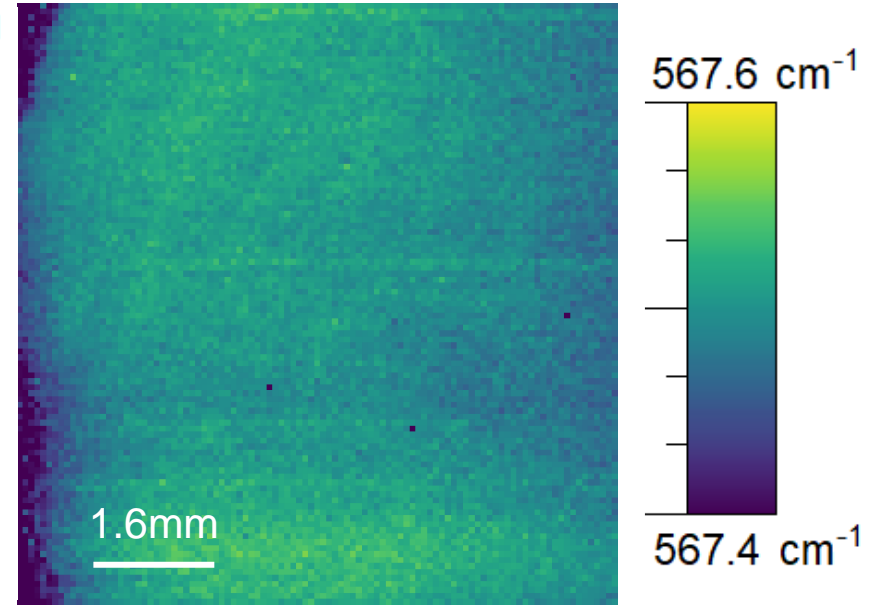
XRT transmission



FWHM E₂

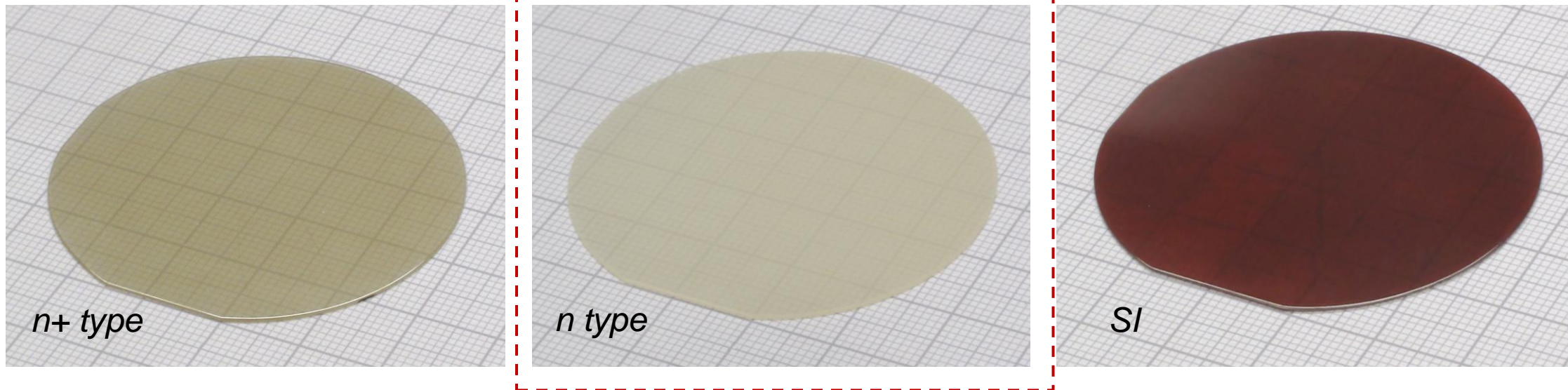


Raman shift E₂



The area inside of "propellers" region is characterized by a lower free carriers concentration.
No effects of strain/stress related to the presence of "propellers" are visible.

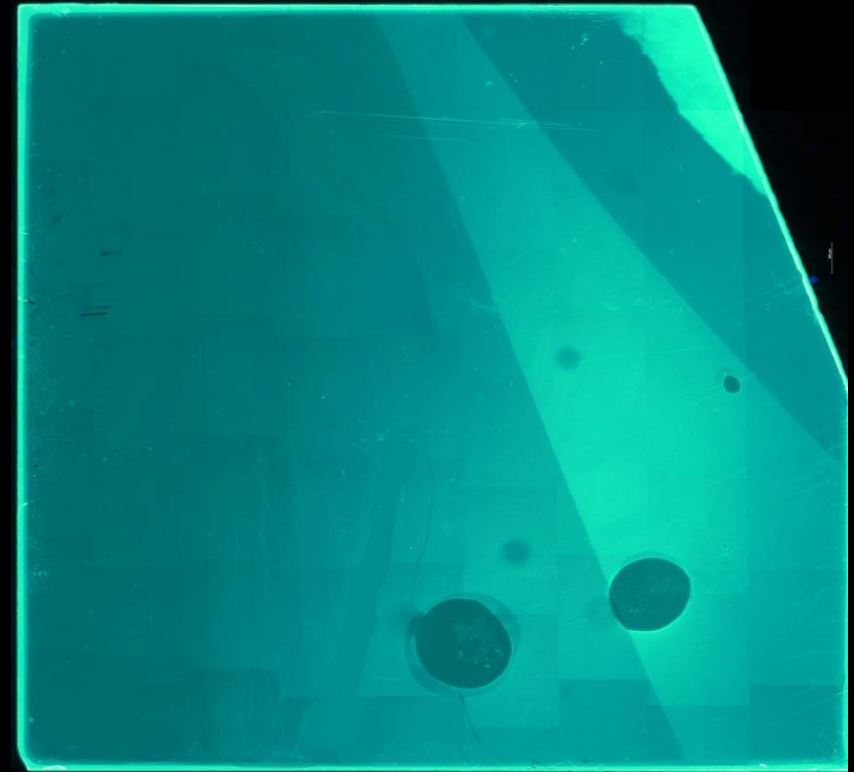
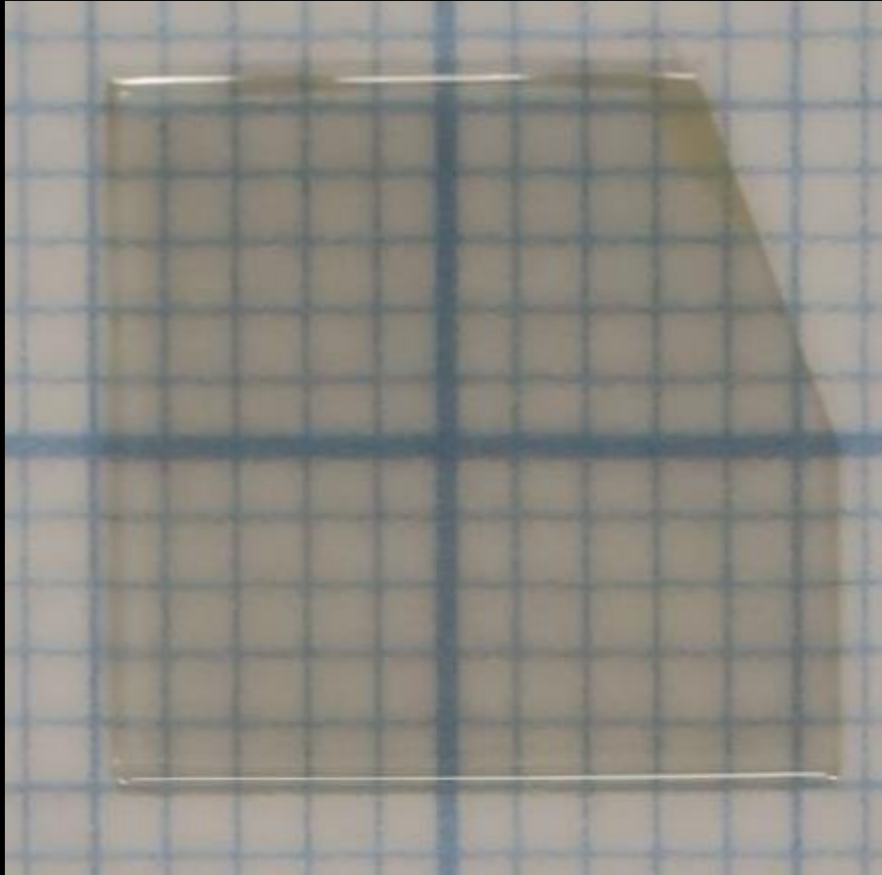
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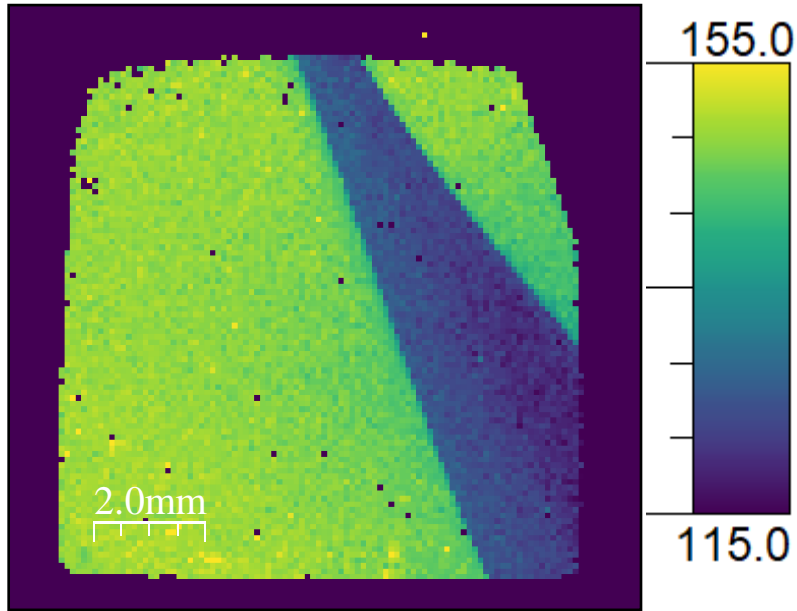
n - Am-GaN substrate

OM (UV)

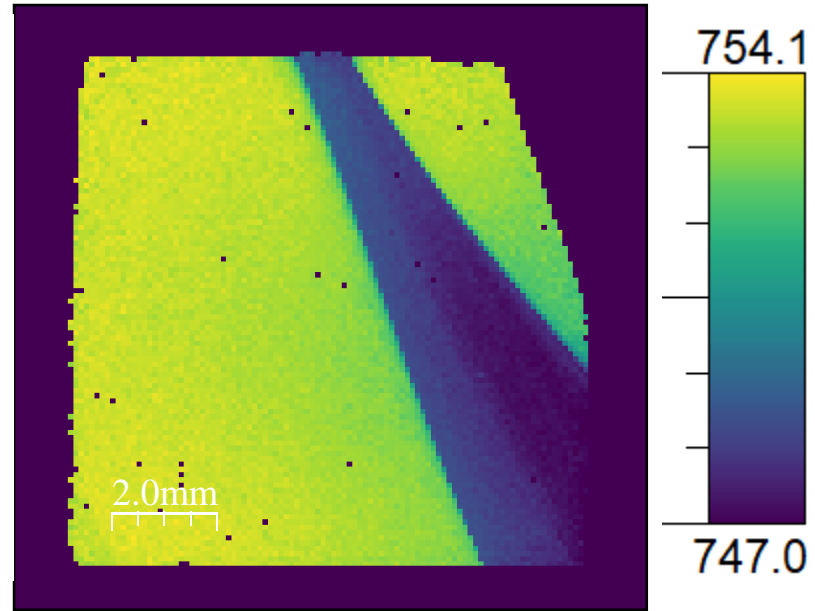


LPP- , LPP+ Raman signature

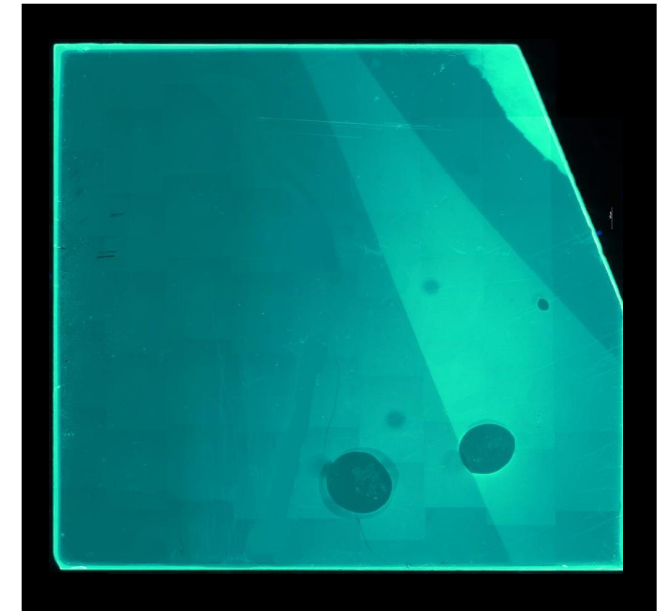
Raman shift LPP-



Raman shift LPP+



OM (UV)

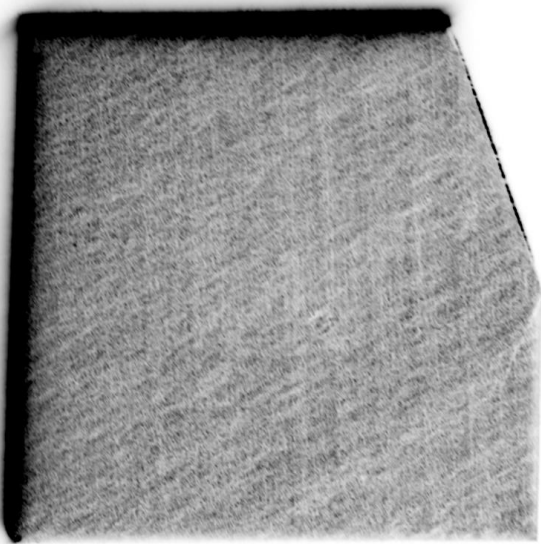


n Am-GaN

The area inside of "propellers" region is characterized by a lower free carriers concentration.

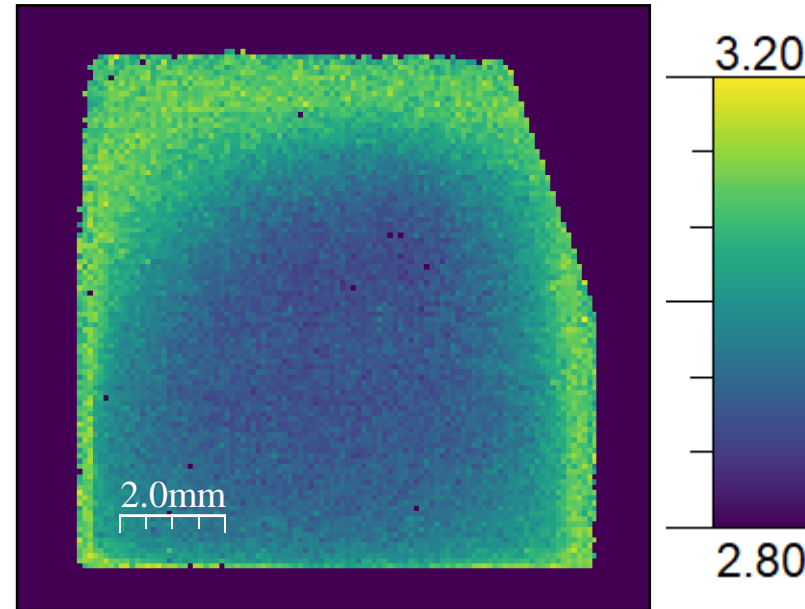
LPP-, LPP+ and E₂ Raman signature

XRT transmission



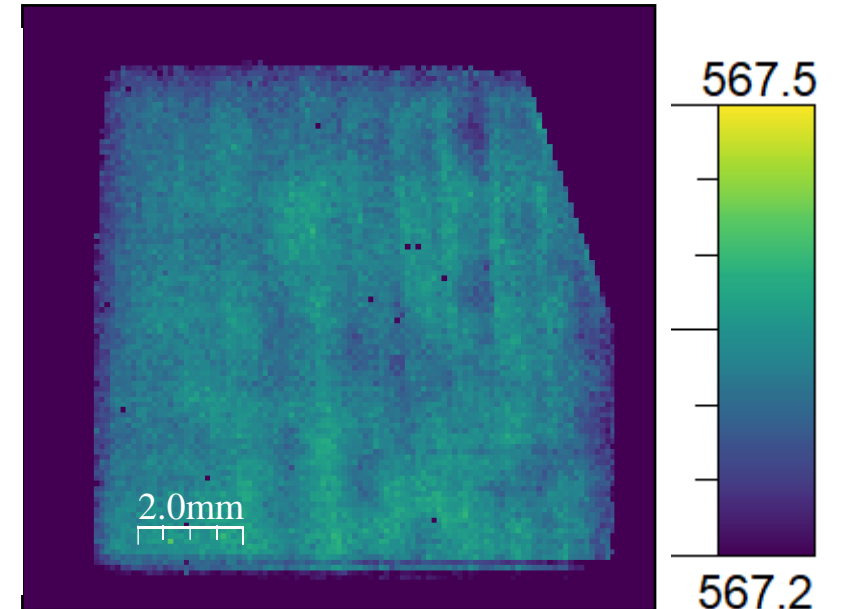
$\bar{2}110$ ↓

FWHM E₂



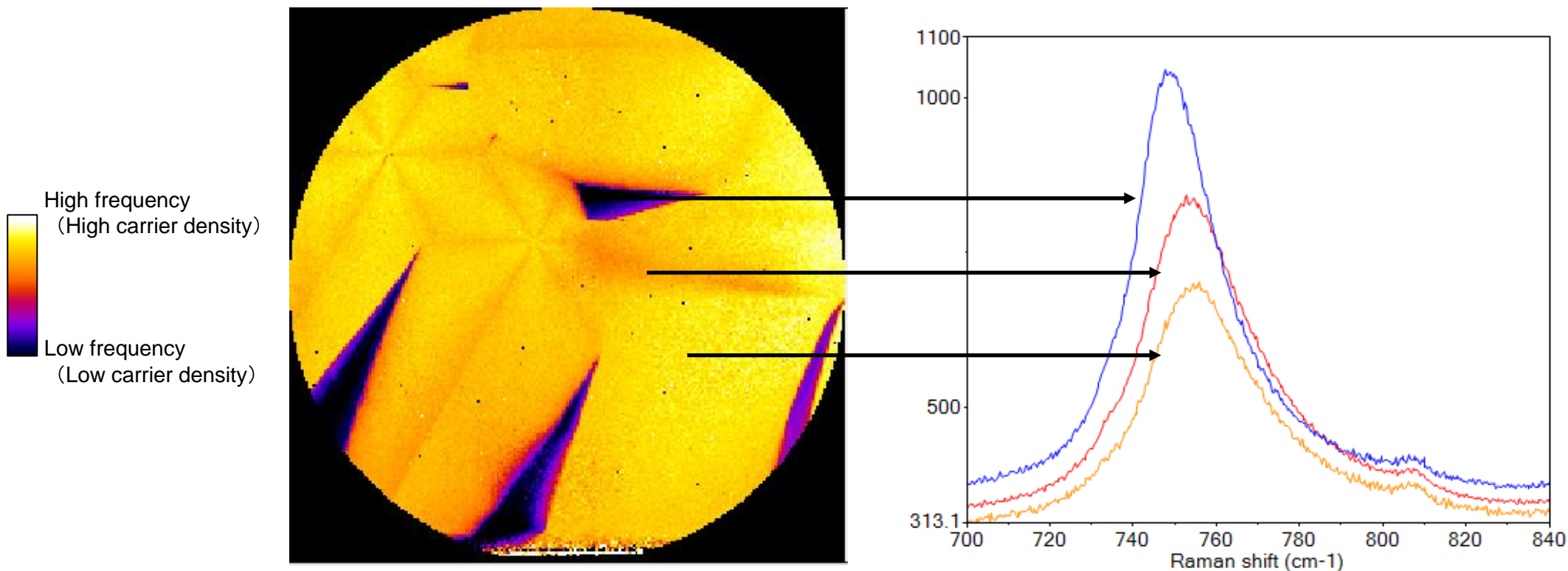
n Am-GaN

Raman shift E₂



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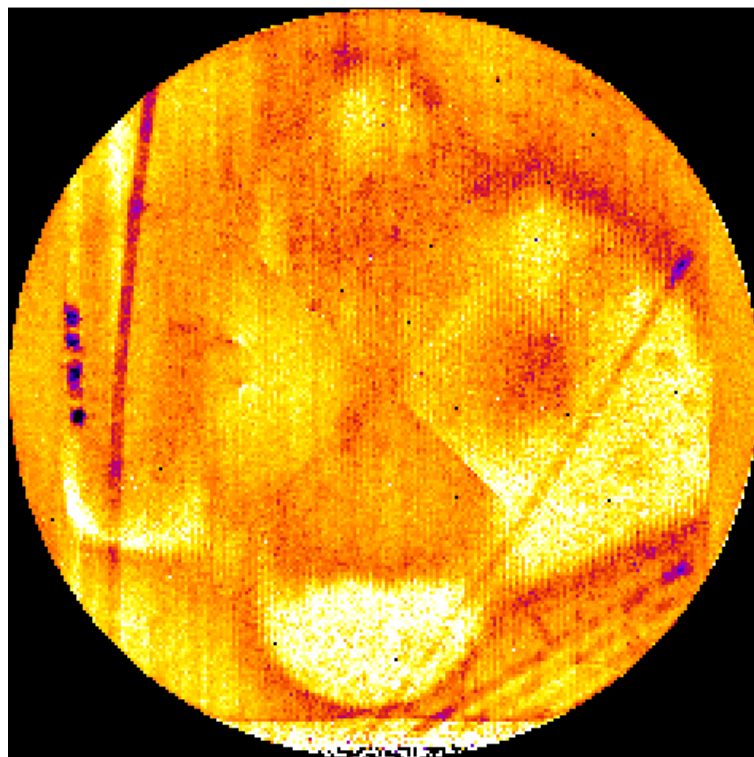
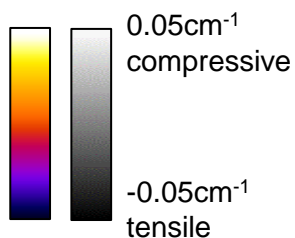
Nanophoton Laser Raman Microscope RAMANdrive



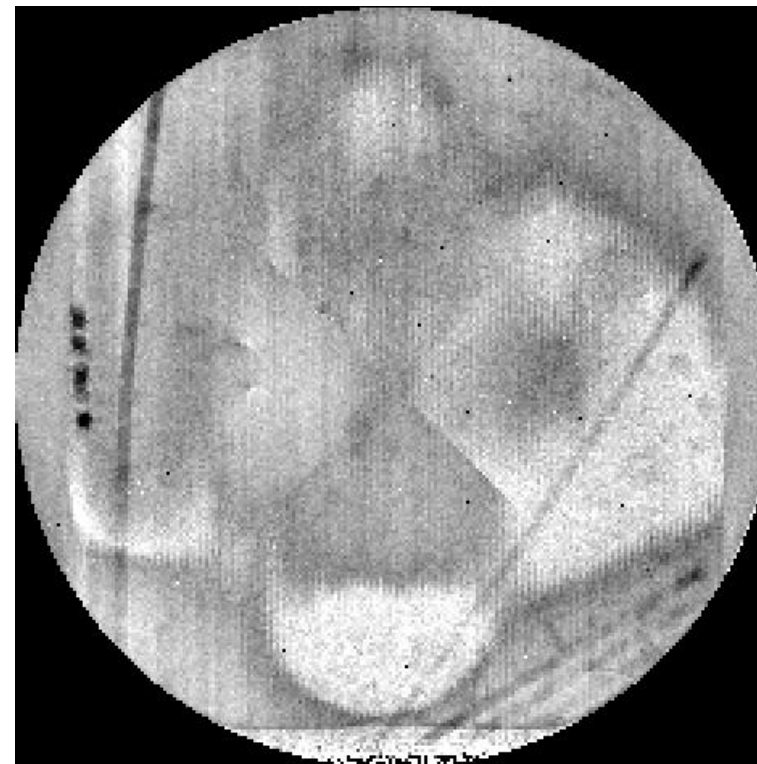
Full wafer AreaFlash mapping condition
 Excitation 532.08 nm, x100/ NA 0.9, 9.7×10^4 W/cm²,
 Grating 2400 gr/mm, Slit 50 μ m, Pixel size 100 μ m x 100 μ m,
 AreaFlash size 80 μ m x 80 μ m, 0.2s/Area,
 236 x 236 pixels, measured area 23.6 mm x 23.6 mm, time 4 hr 27 min

Shugo Nitta NU Japan

Nanophoton Laser Raman Microscope RAMANdrive



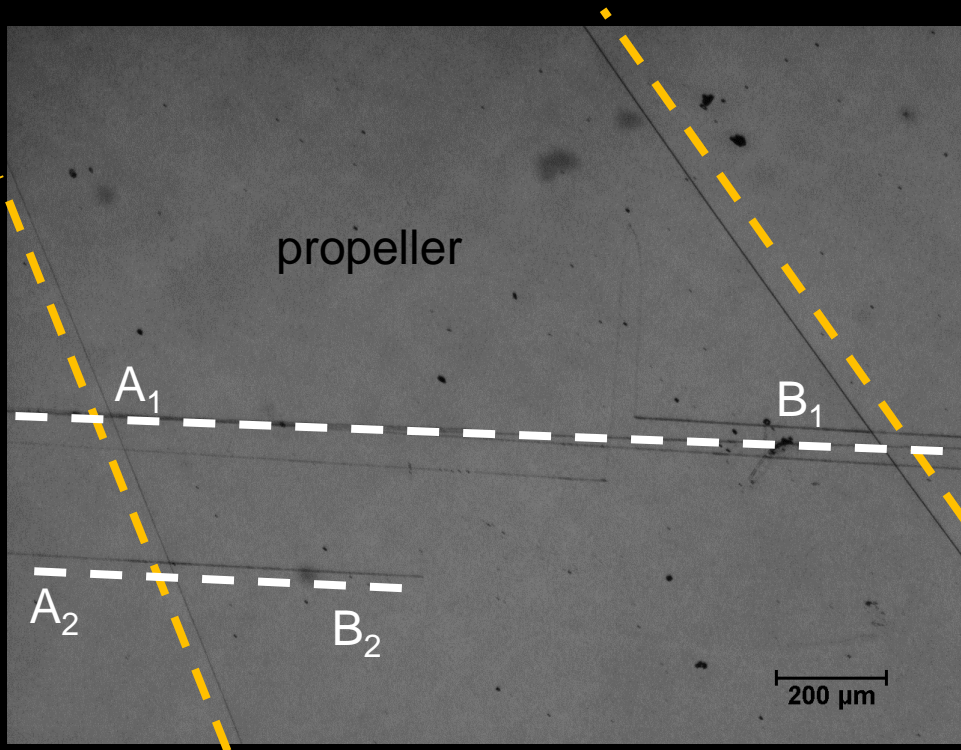
E_2^H Raman peak shift mapping



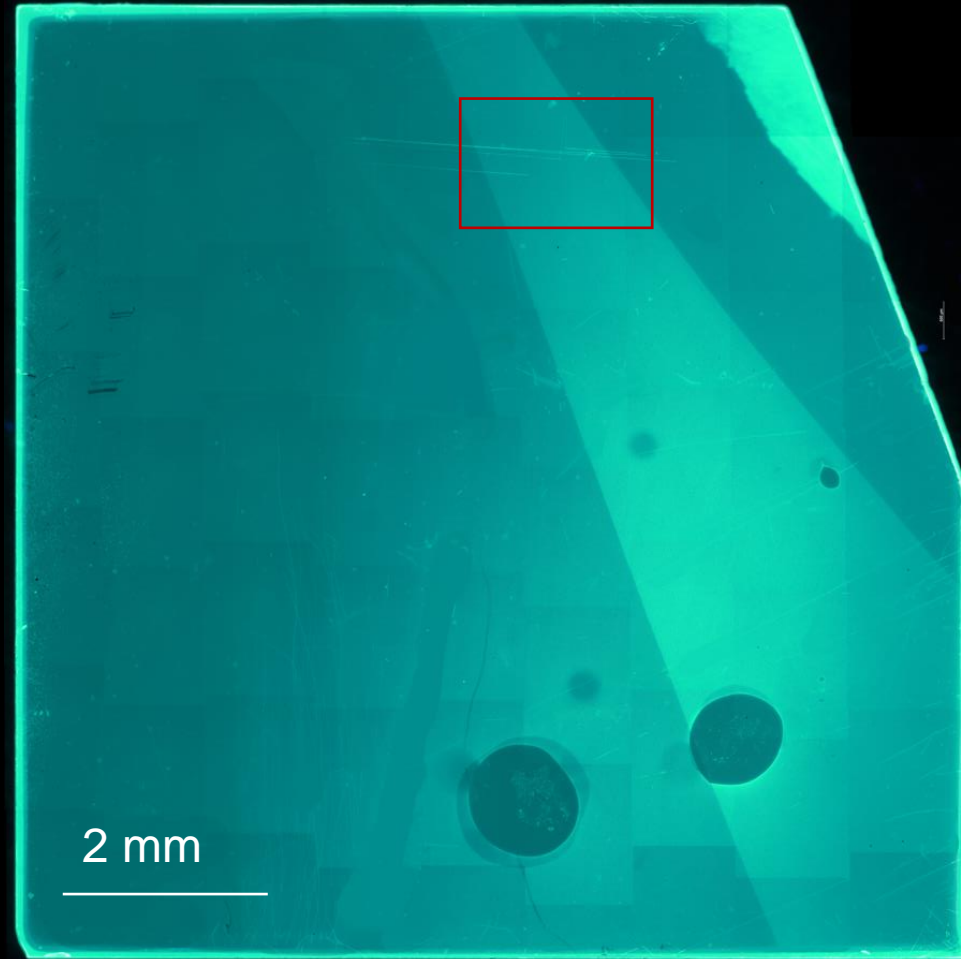
E_2^H Raman peak shift mapping (gray scale)

n - Am-GaN substrate – results of Photo-etching

Photo-etched (PE) for 40 min. in KSO-D solution

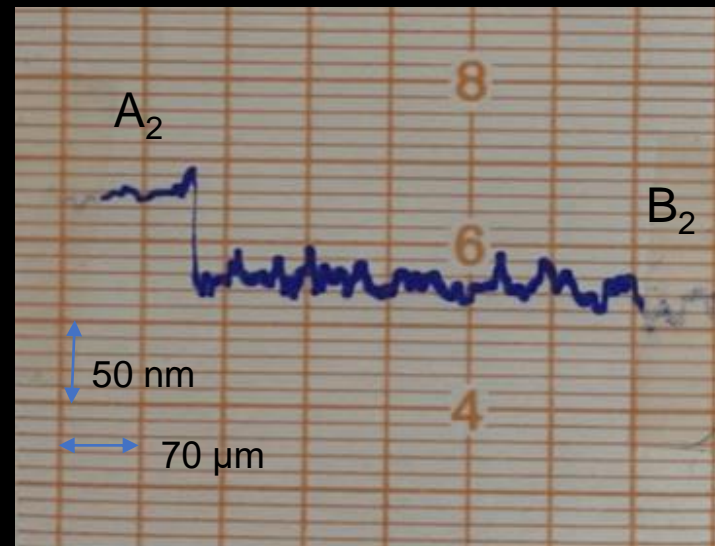
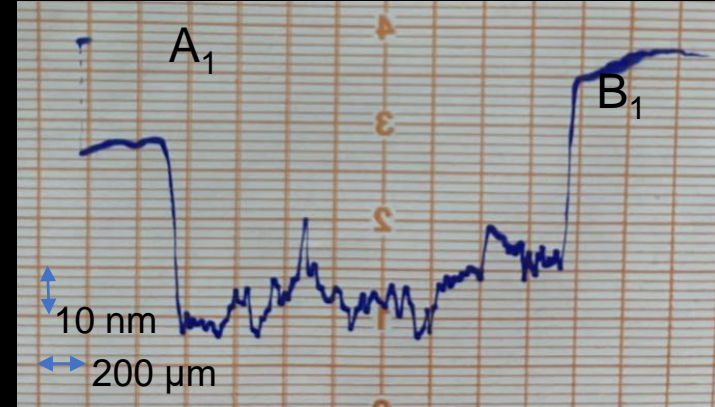
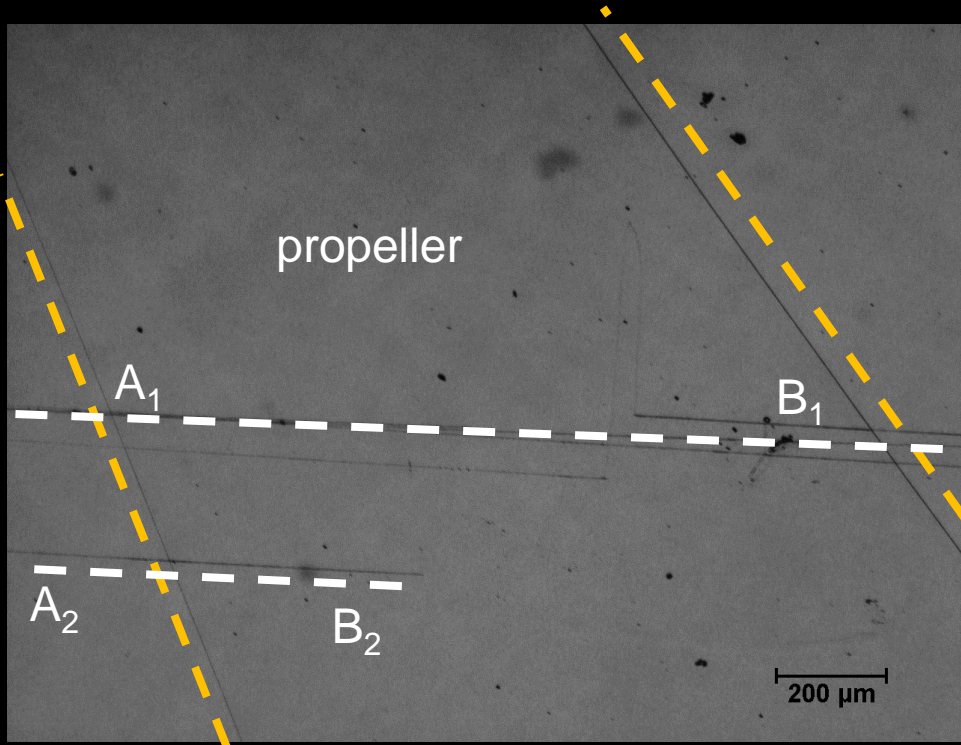


DIC image of the sample surface after PE



UV map of the Am-GaN sample

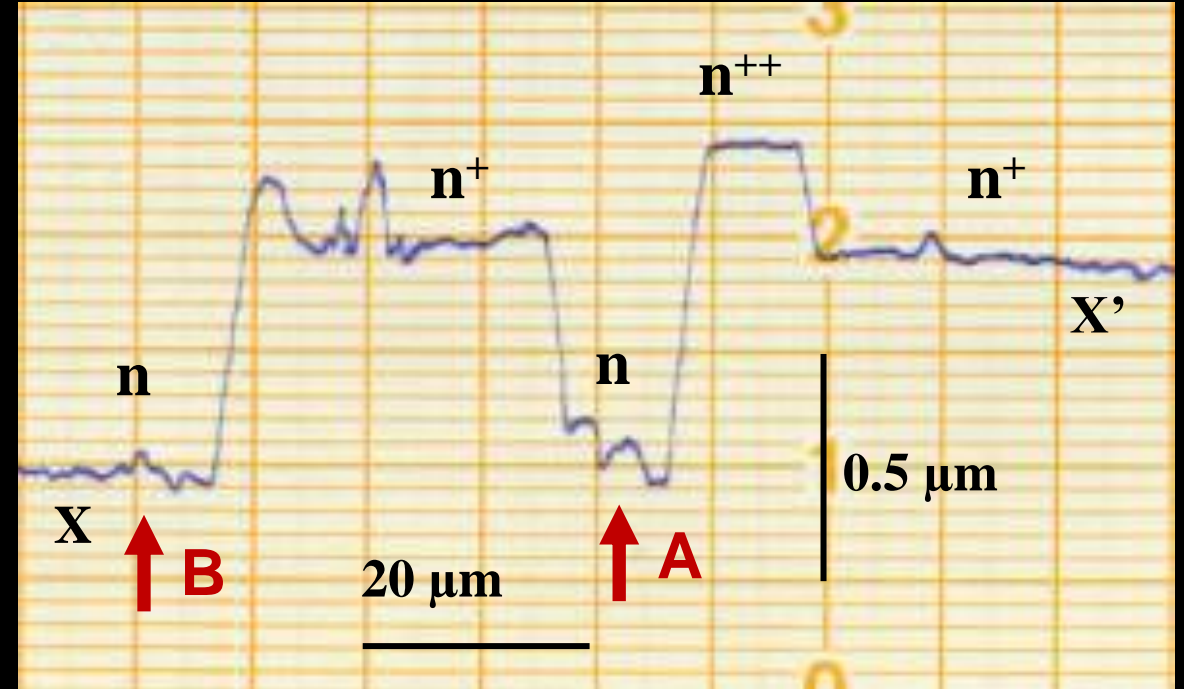
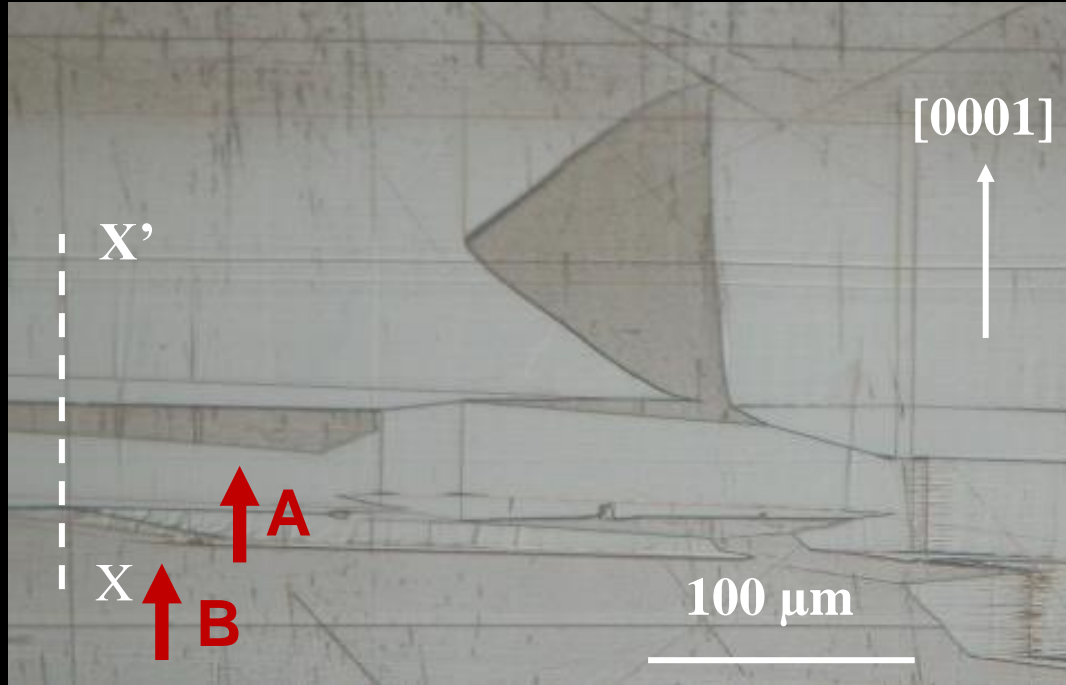
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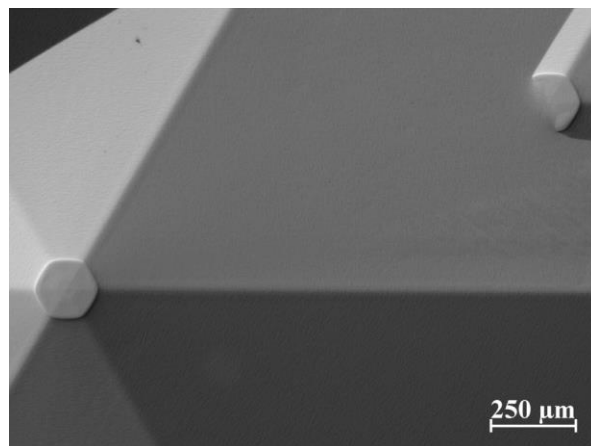
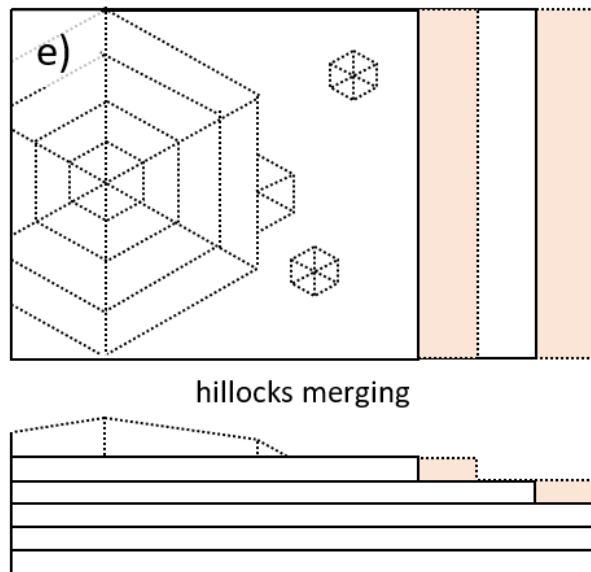
Results of PEC on cross-section of the HVPE-GaN

HVPE-GaN form foreign substrate



Solution for this „problem” ...

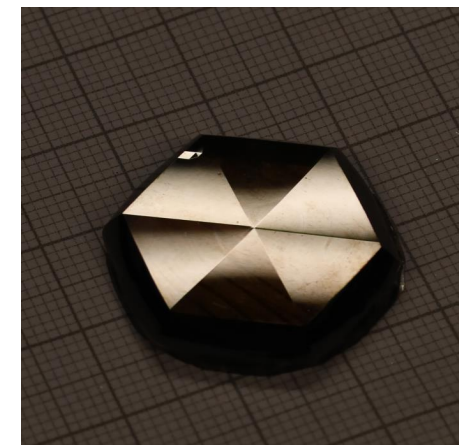
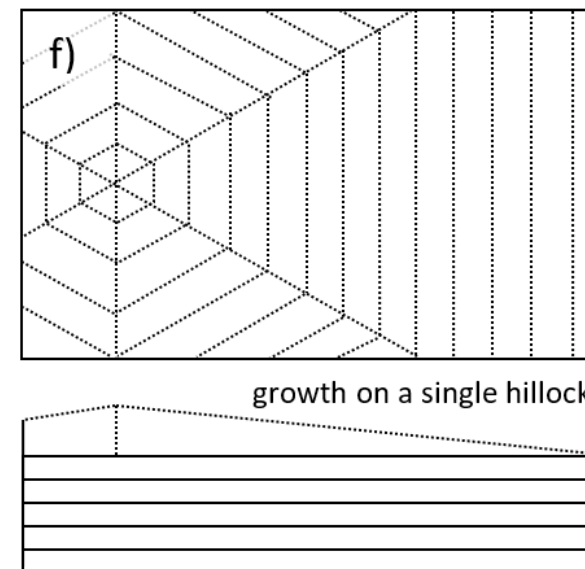
Growth model



Fast transition

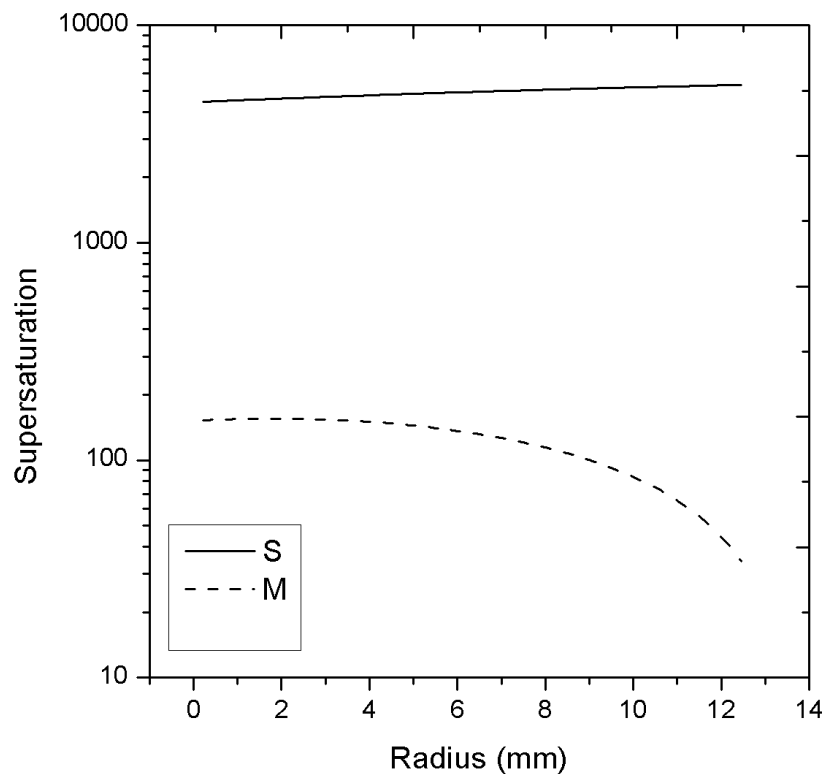


HVPE
Relatively easy



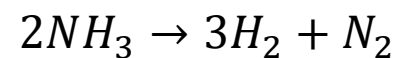
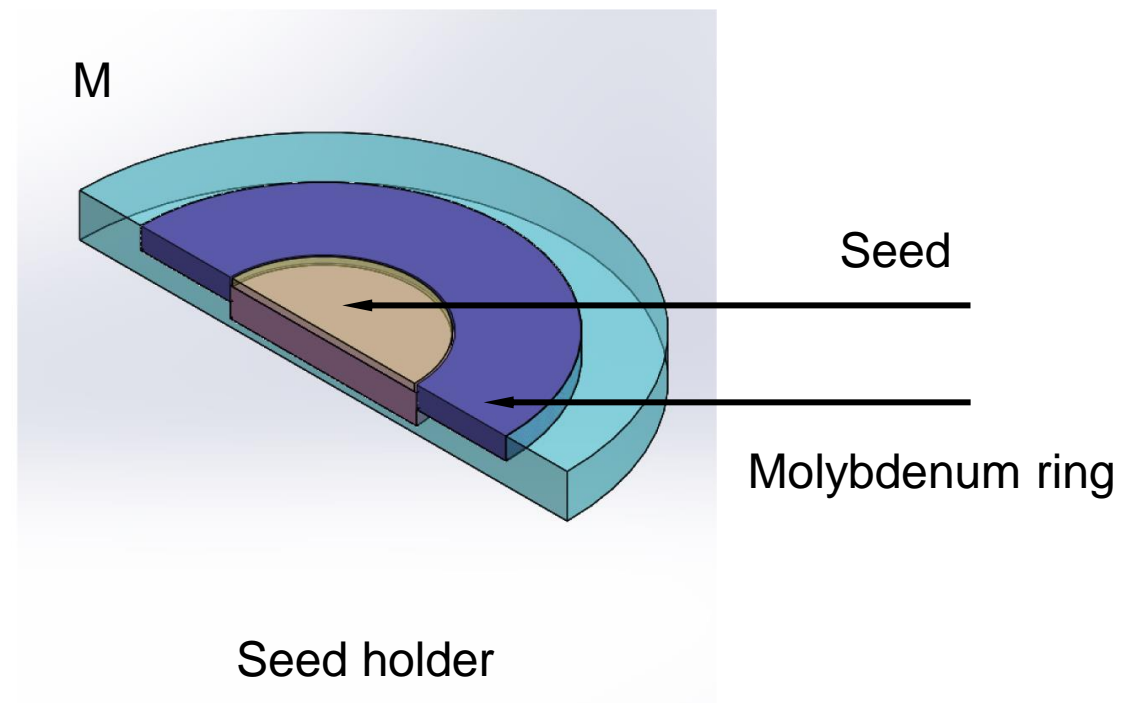
Ammonothermal
Potentially difficult

Solution for fast transition between growth modes - HVPE

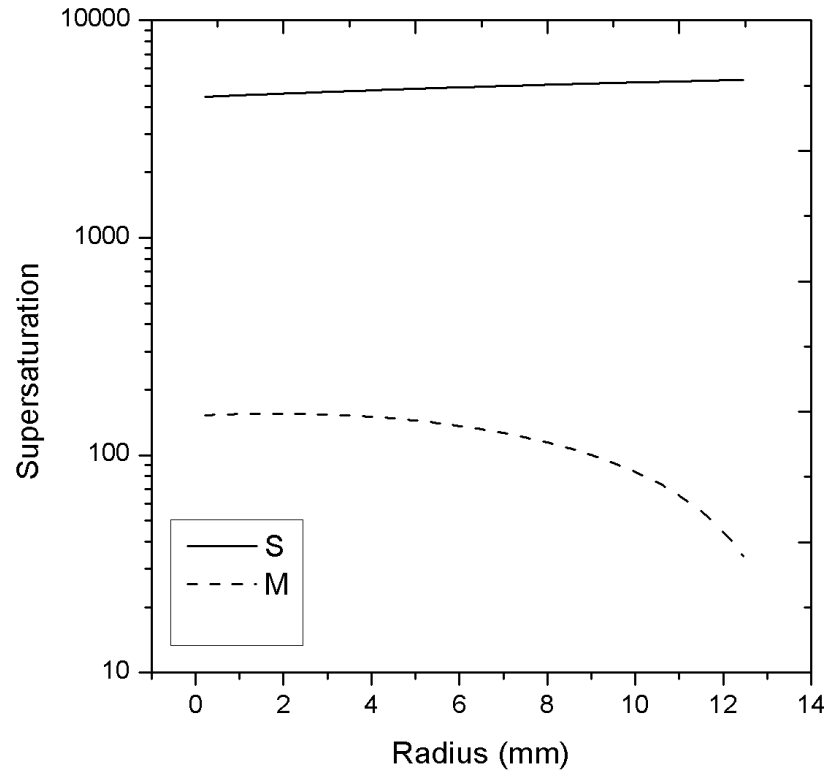


Middle of the seed

Edge of the seed

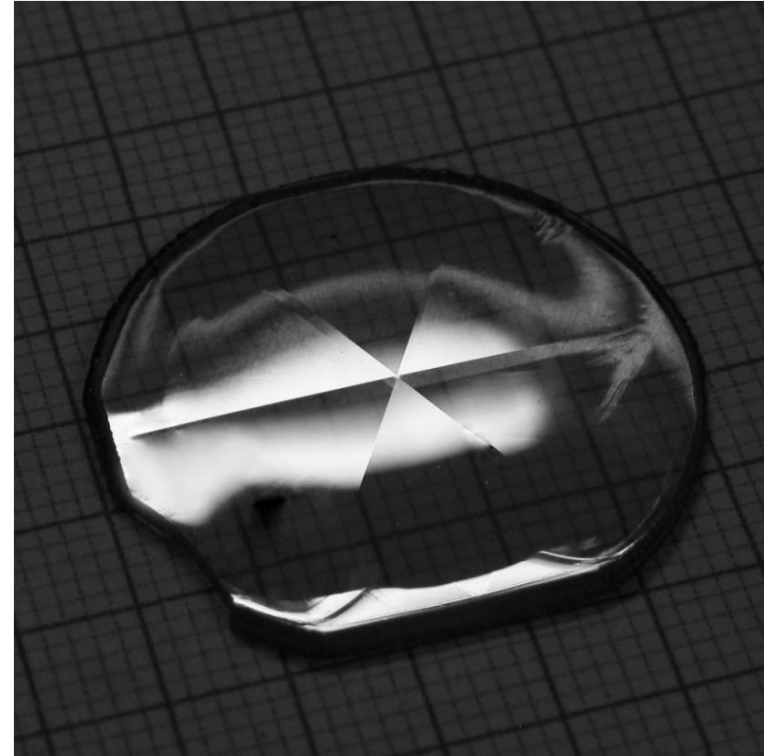


Solution for fast transition between growth modes - HVPE

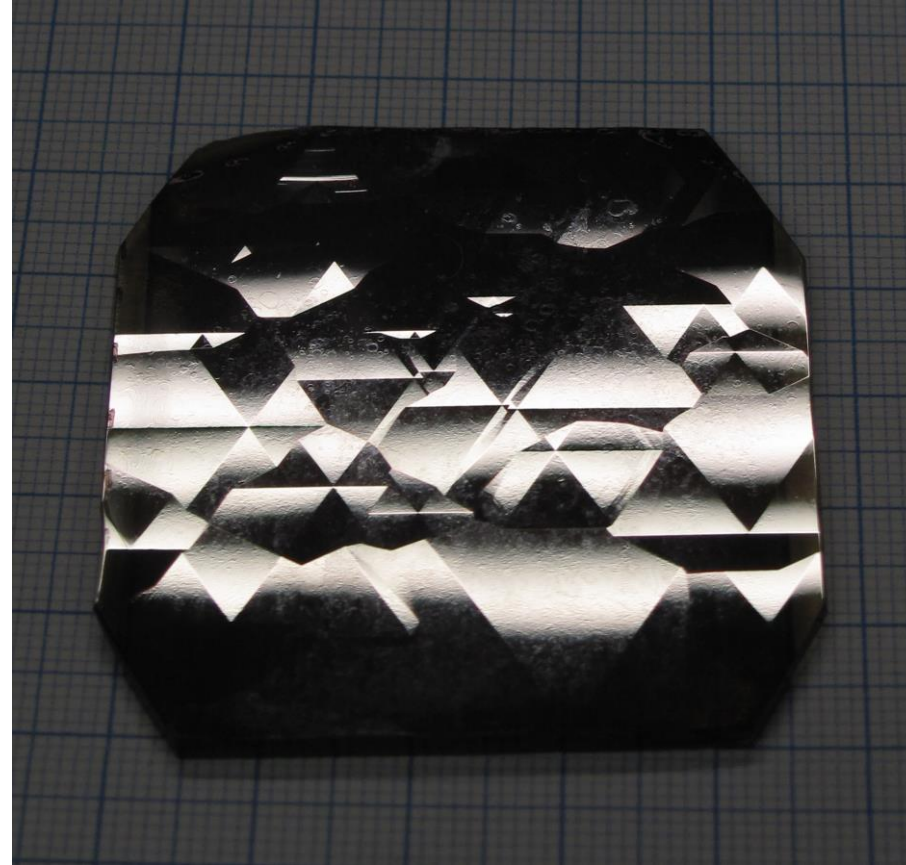


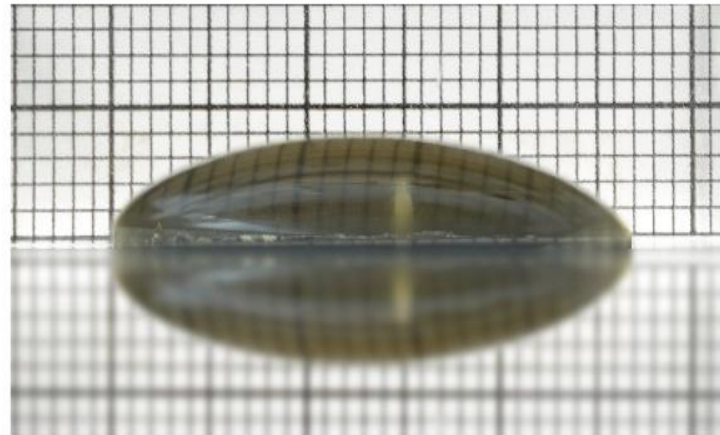
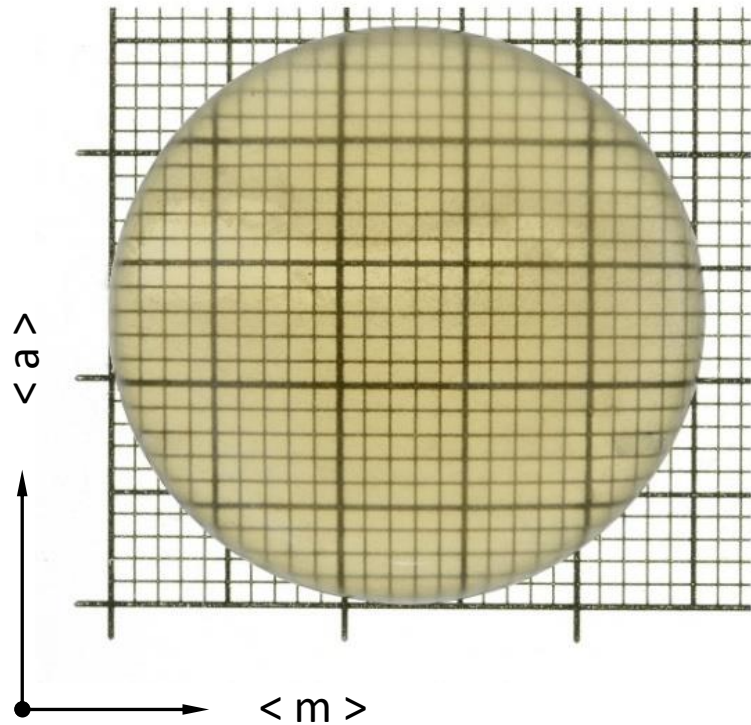
Middle of the seed

Edge of the seed

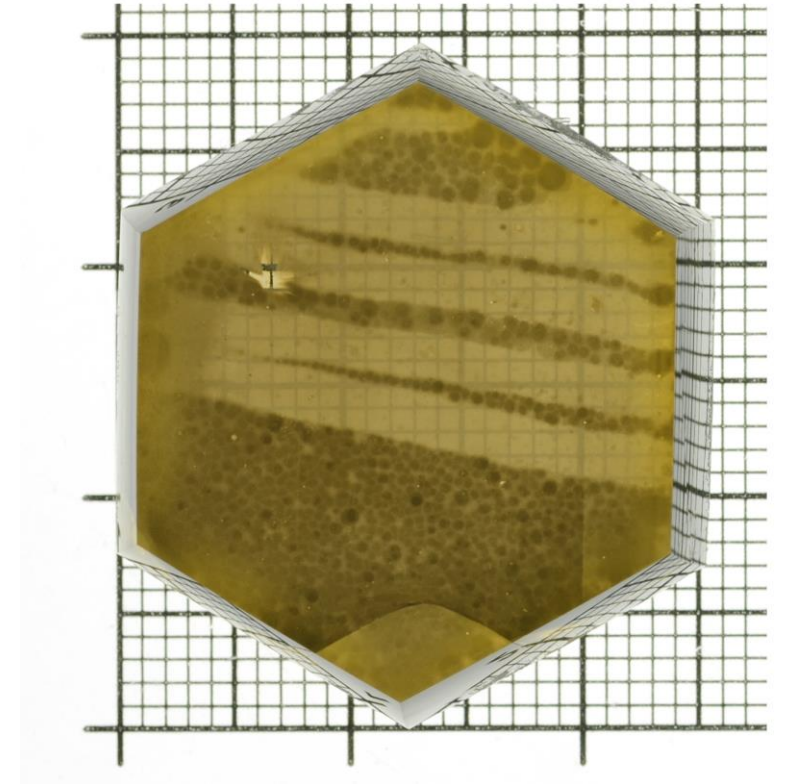


HVPE-GaN

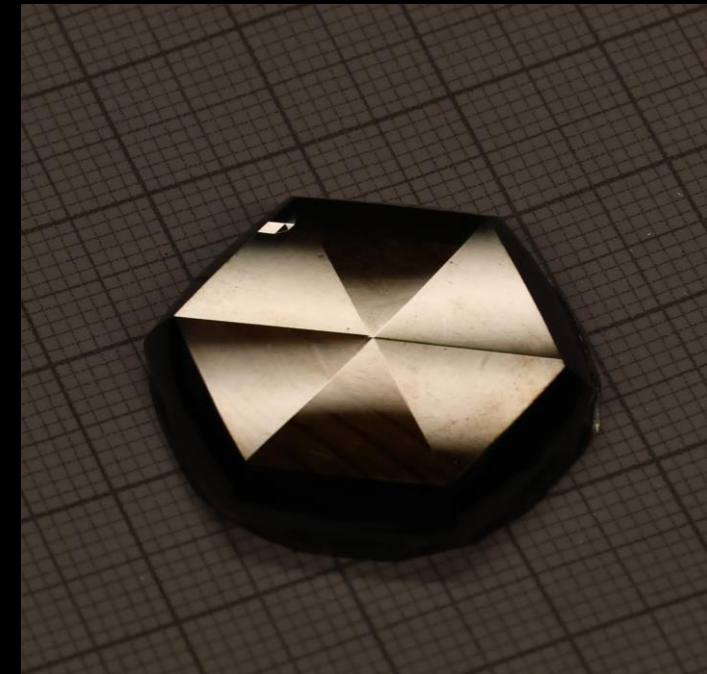
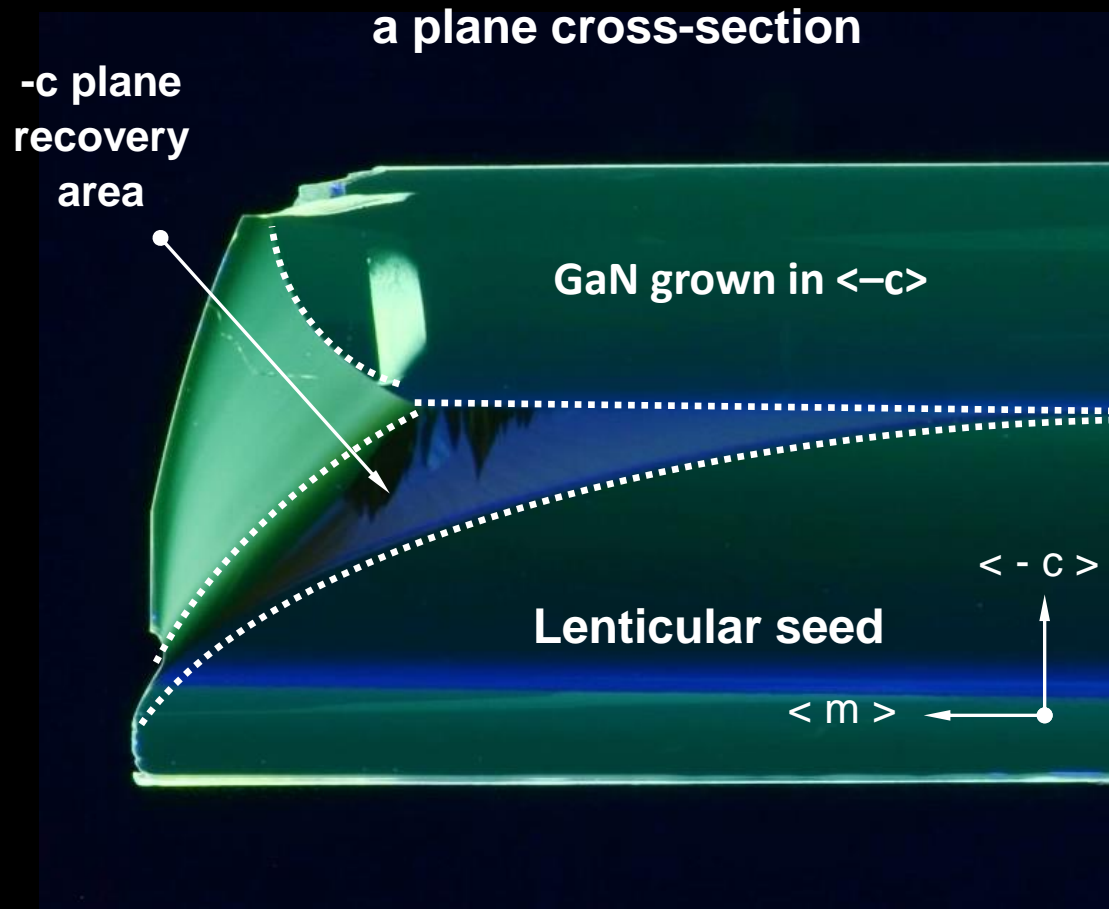




Lenticular seed



Inspection of cross-sections under UV illumination



Summary

- It was found that in the area with triangular defects, the concentration of carriers is lower than in the rest of the crystal;
- Formation of such areas is associated with a change in the growth morphology (presence of step-meandering);
- Occurrence of step-meandering is related with interconnection of adjacent growth hills;
- When m-steps on the sides of two adjacent hillocks form an angle of 120 degrees, an unstable a-step is formed.
- It leads to the formation of growth disturbances which may result in the formation of inhomogeneous areas with lower carrier concentration in the volume of the growing crystal.
- **The observed inhomogeneities in carrier concentration are small enough that they do not introduce measurable stresses in n/n+ Al-GaN substrates.**

Acknowledgments

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Thank you for your attention