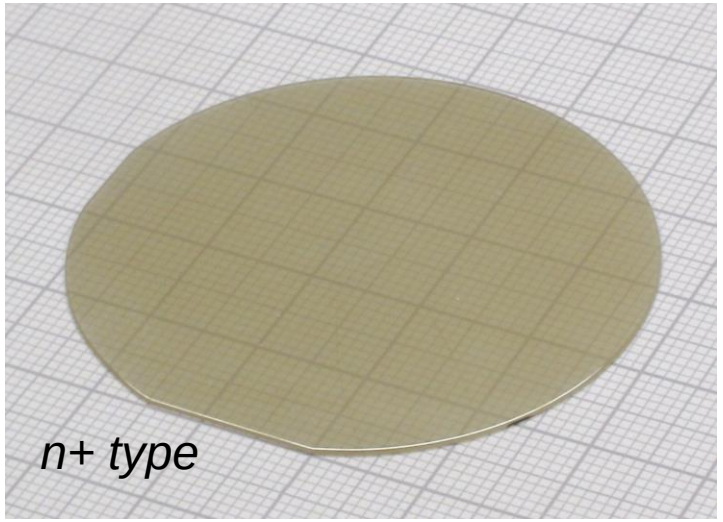
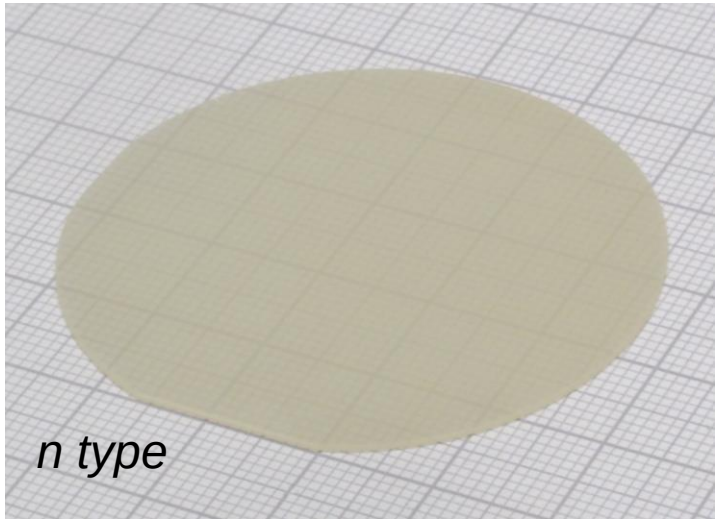
Exploring Gallium Nitride Bulk Crystal Growth

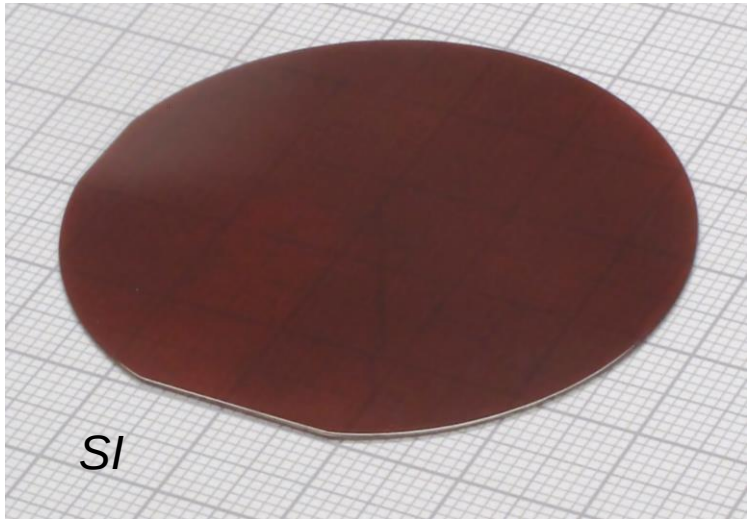
T. Sochacki[1], M.A. Zajac[1], M. Paillet[2], S. Juillaguet[2], R. Kucharski[1], K. Grabianska[1], A. Jaroszynska[1], K. Sierakowski[1], J.L. Weyher[1], L. Kirste[3] and M. Bockowski[1]

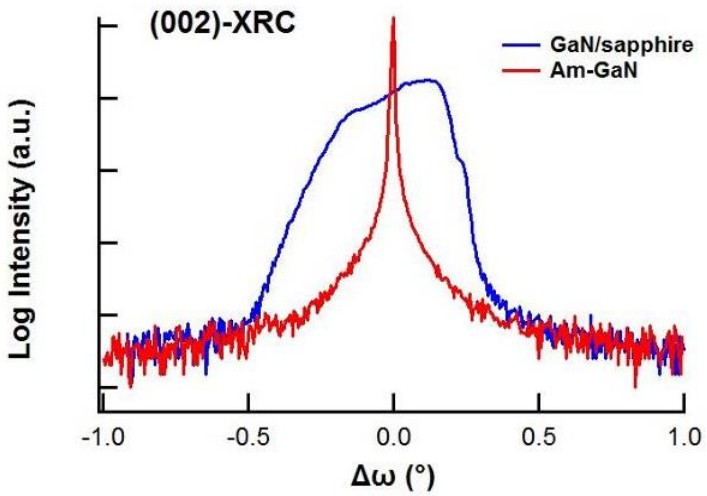
[1] Institute of High Pressure Physics Polish Academy of Sciences, Warsaw, Poland
[2] Laboratoire Charles Coulomb (L2C), University of Montpellier, CNRS, Montpellier, France
[3] Fraunhofer Institute for Applied Solid State Physics (IAF), Freiburg, Germany
e-mail: tsochacki@unipress.waw.pl

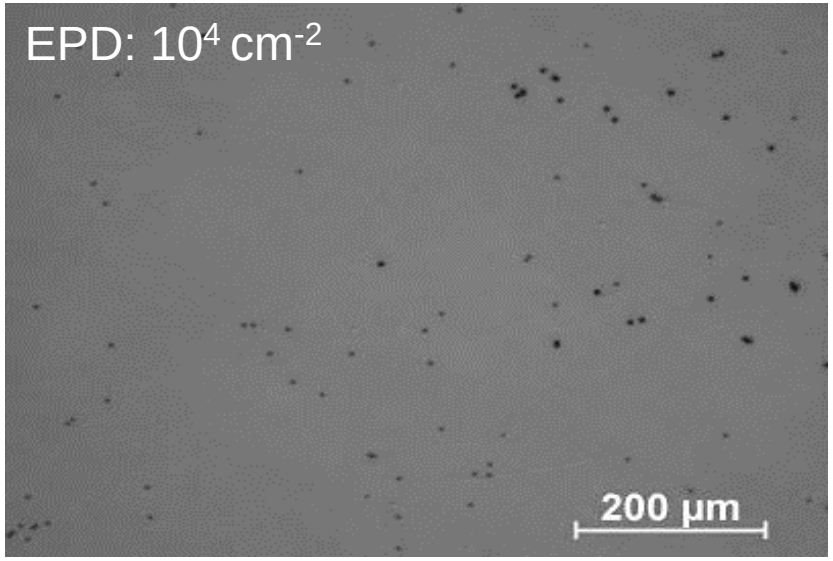
2 inch Am-GaN substrates – electrical properties



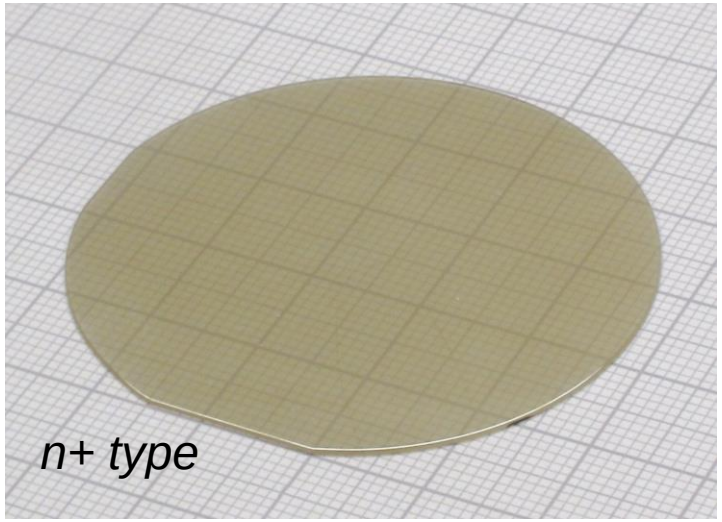


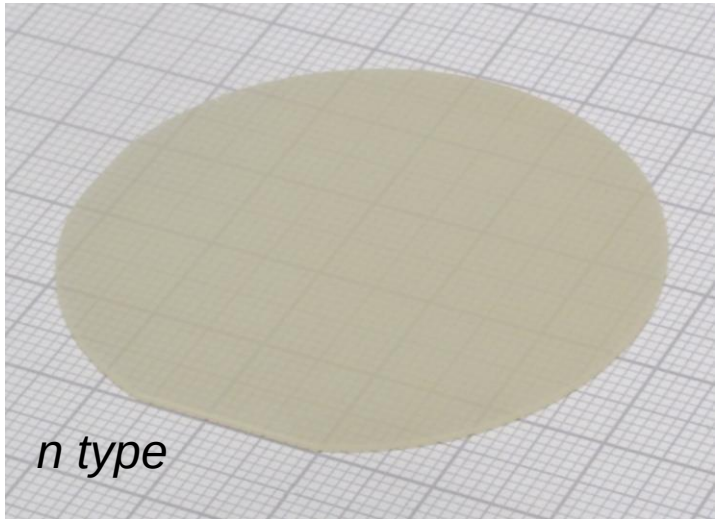


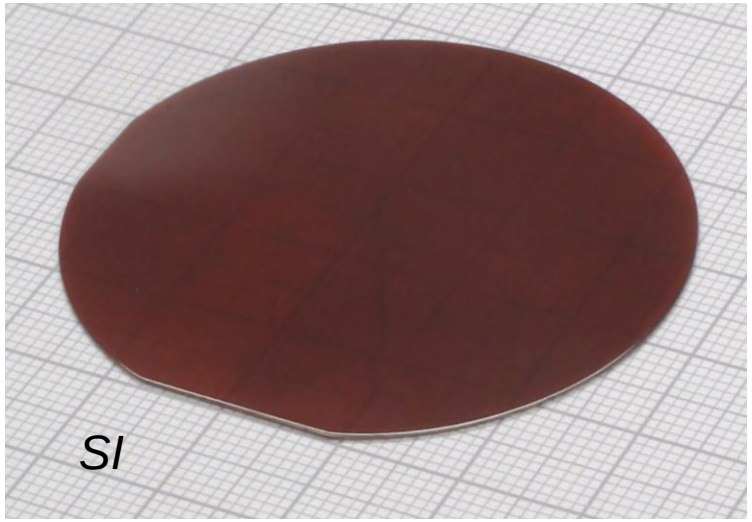




2 inch Am-GaN substrates – electrical properties



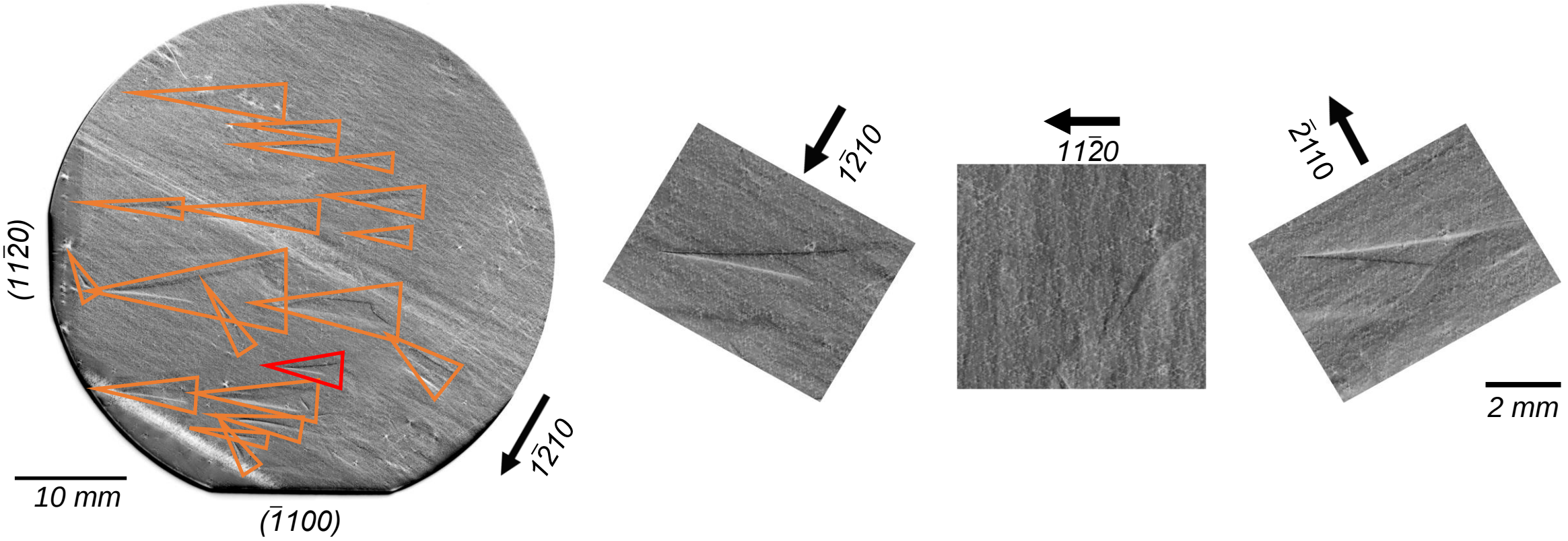




Material type	Conductivity type	Carrier concentration [cm^{-3}]	Carrier mobility [cm^2/Vs]	Resistivity [Ωcm]
High carrier concentration	**n+ type**	**~10^{19}**	~150	10^{-3}
Low carrier concentration	**n type**	**~10^{18}**	~250	10^{-2}
High resistivity (Mn-doped)	**semi-insulating (SI)**	-	-	**≥10^{8}**

Uniformity of electrical properties.

Triangular areas – structural inhomogeneities

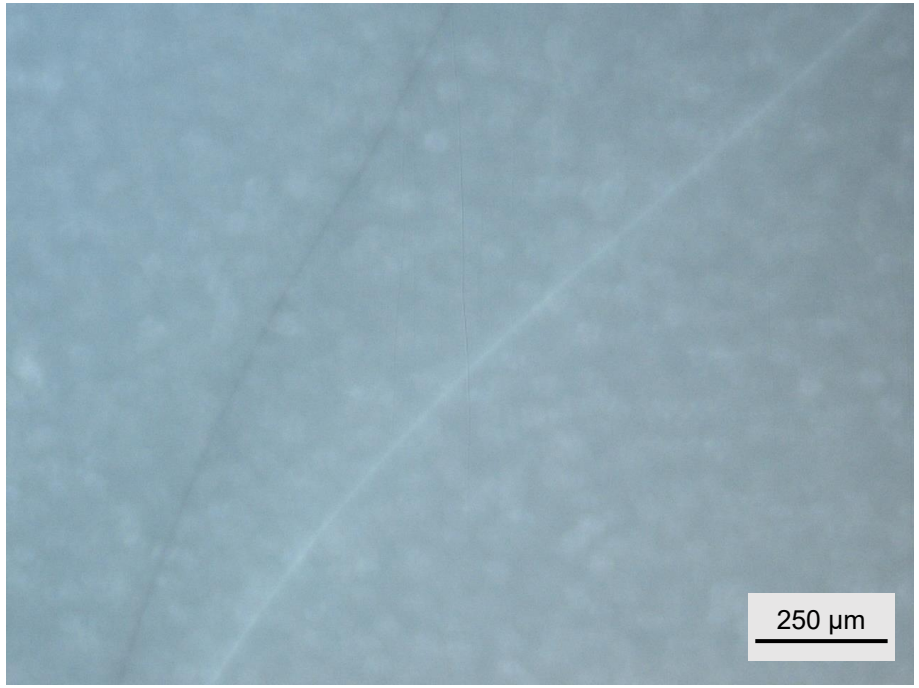


XRT of Am-GaN substrate –
Borrmann effect

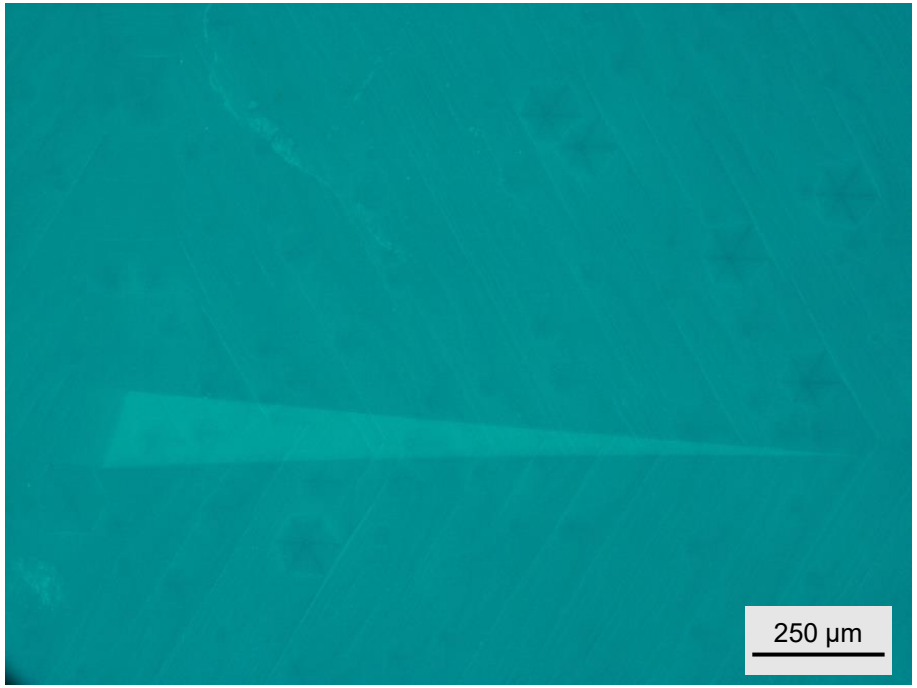
L. Kirste et al., Materials 2021, 14, 5472.

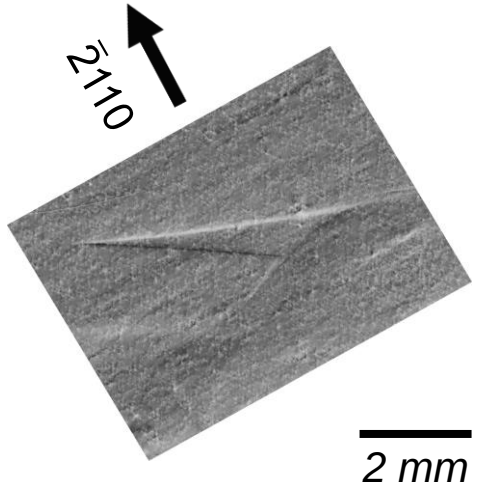
Triangular areas – structural inhomogeneities

n-type Am-GaN after CMP

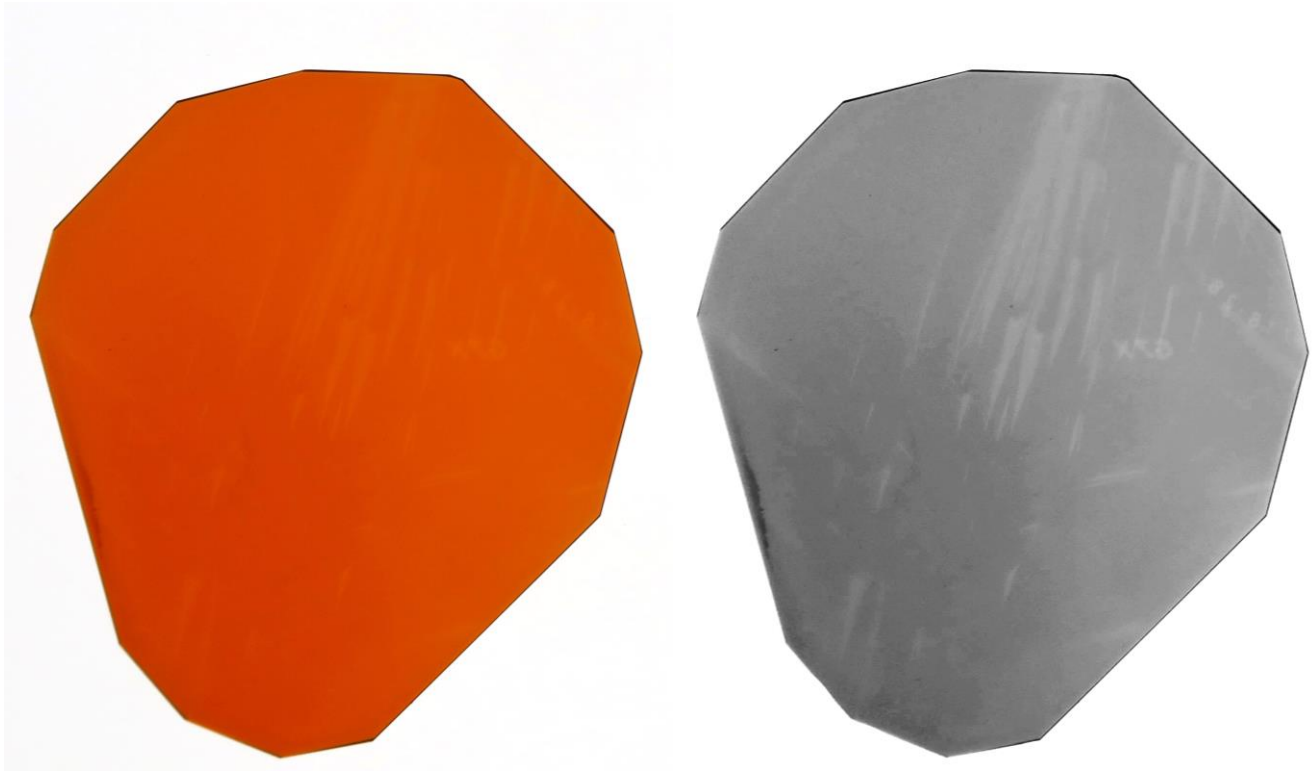


OM under UV light - n-type Am-GaN



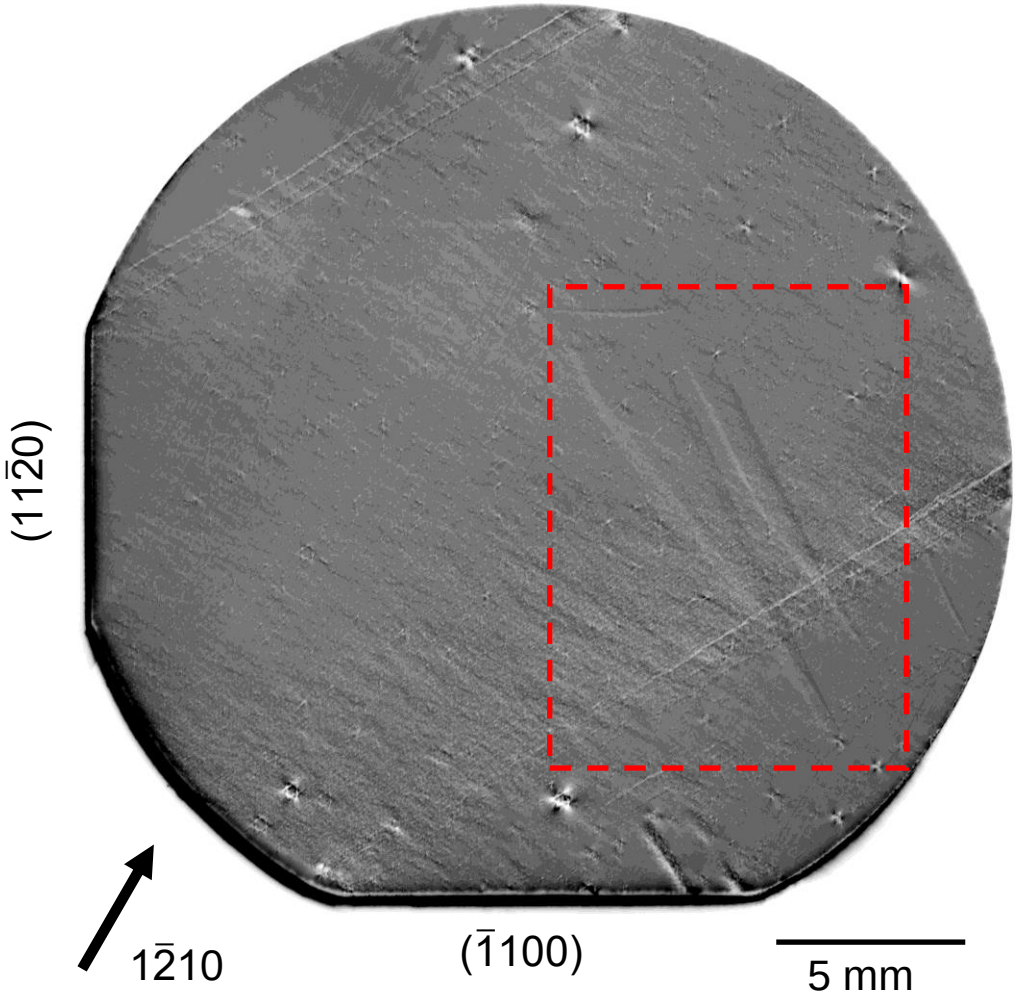


Triangular areas – structural inhomogeneities



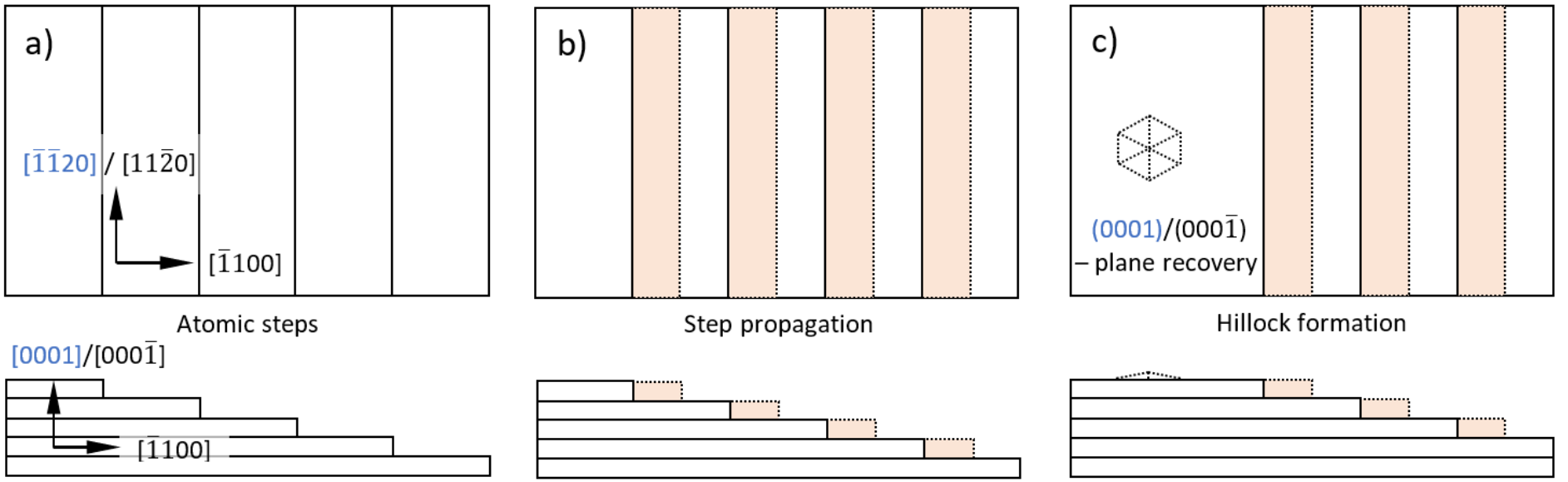
SI Am-GaN (VIS light)

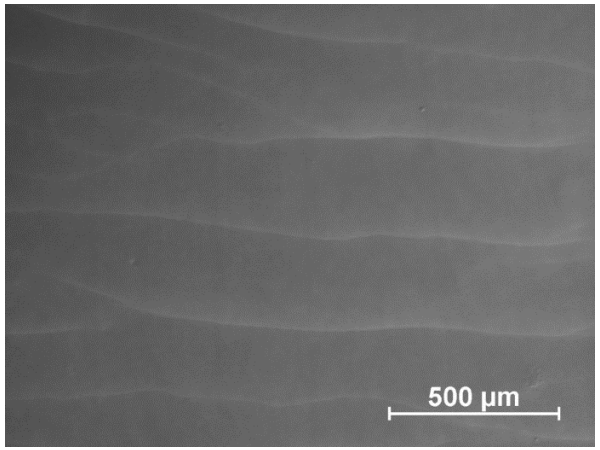
XRT transmission
Cu radiation

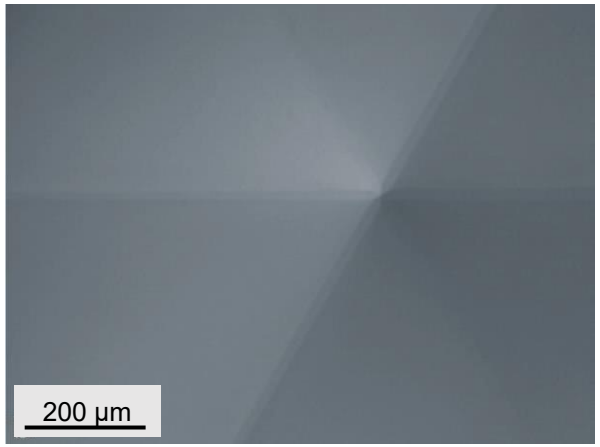


The formation of these inhomogeneities is related to the growth mode of the crystal used for fabrication of the substrate.

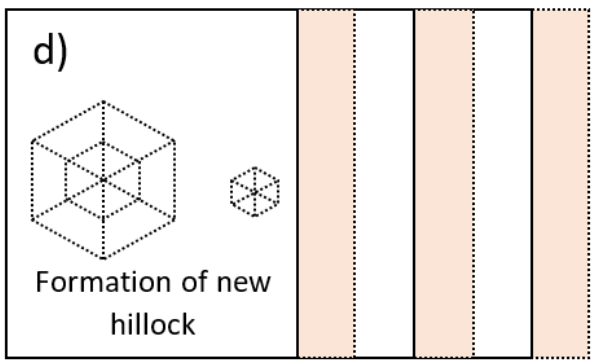
Growth model of the bulk GaN



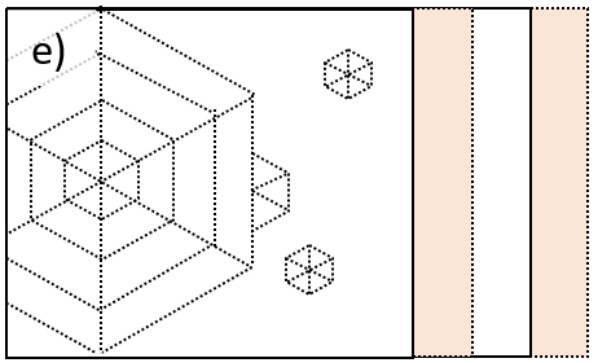




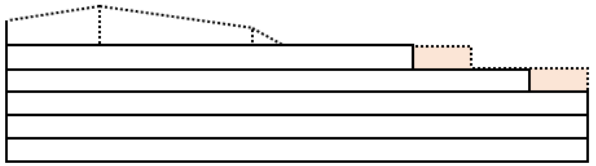
Growth model

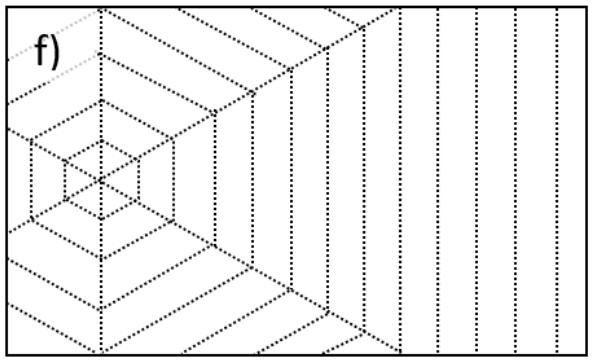


hillock growth

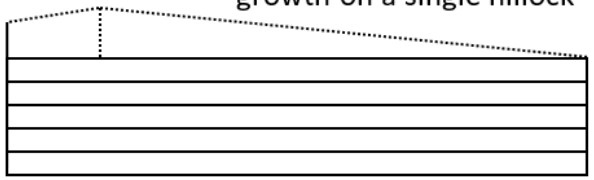


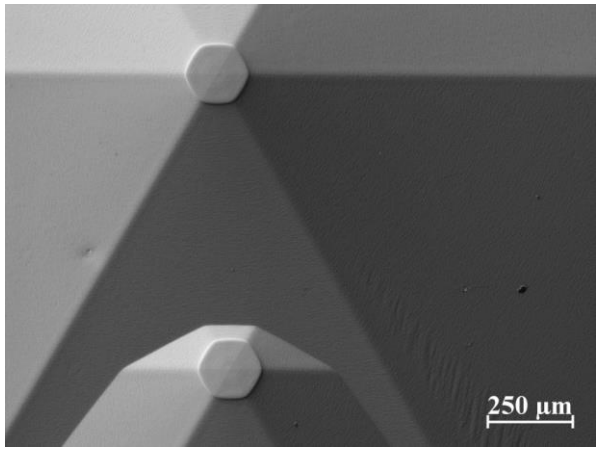
hillocks merging

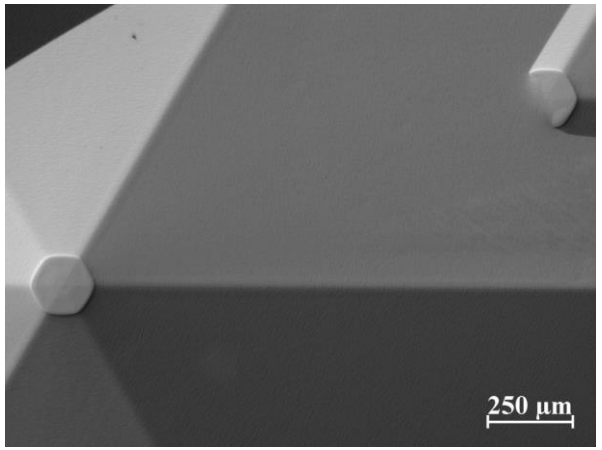


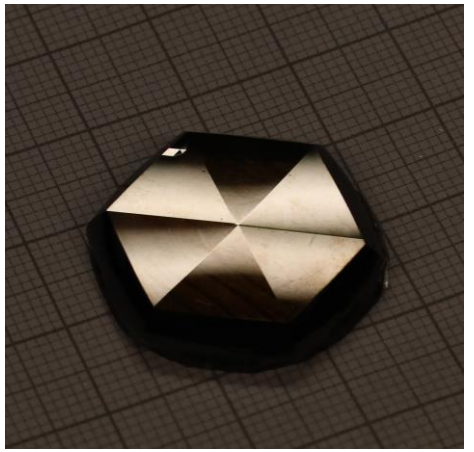


growth on a single hillock

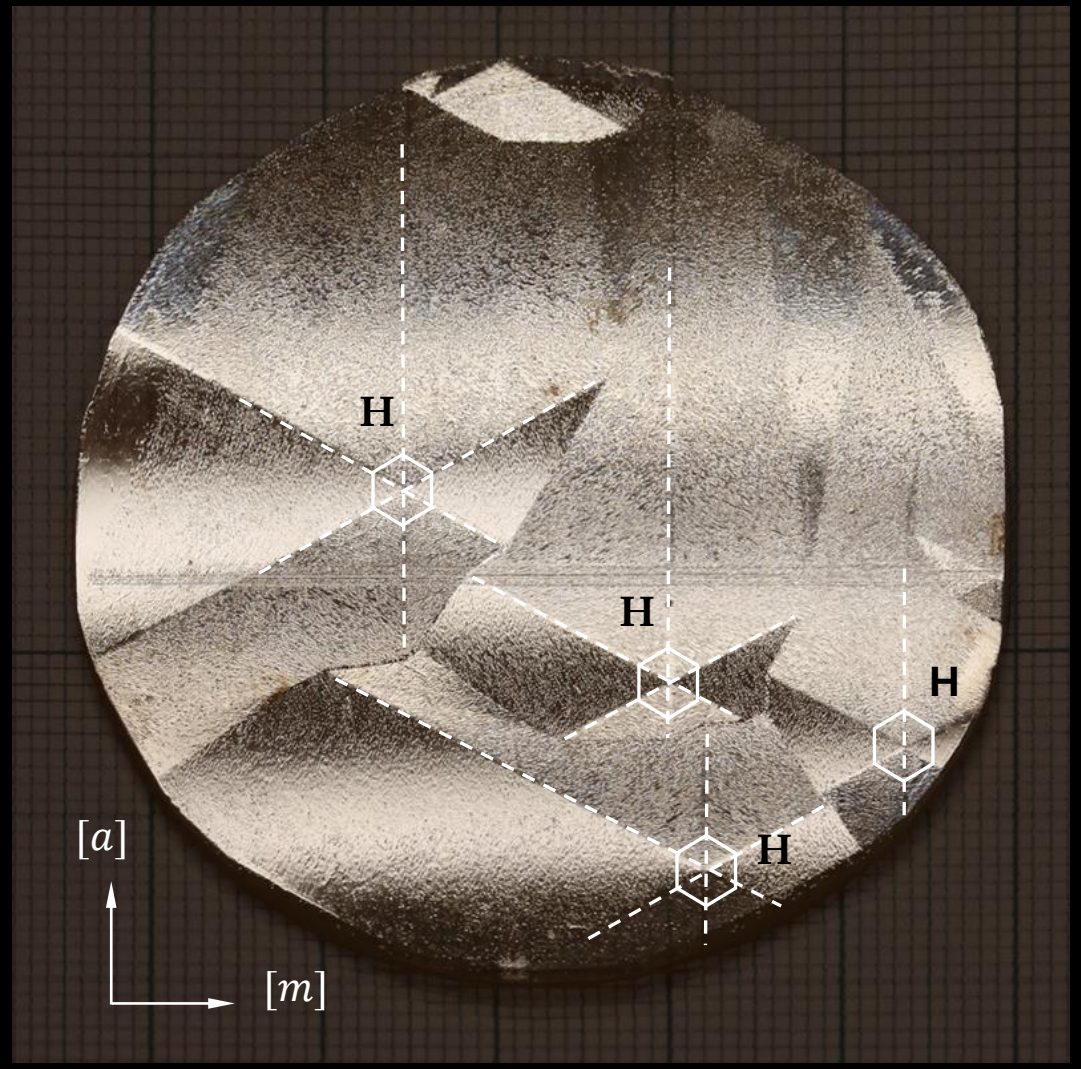




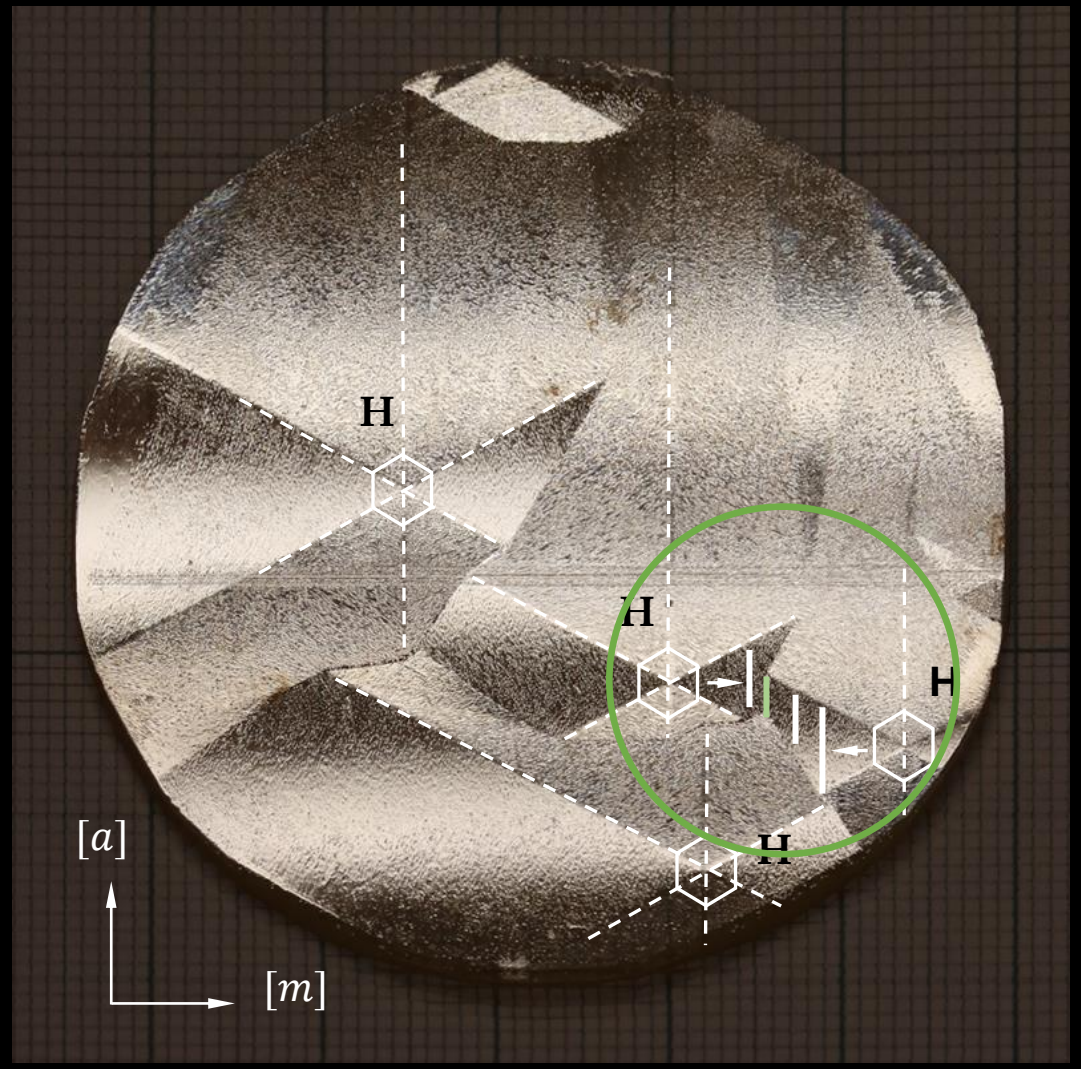


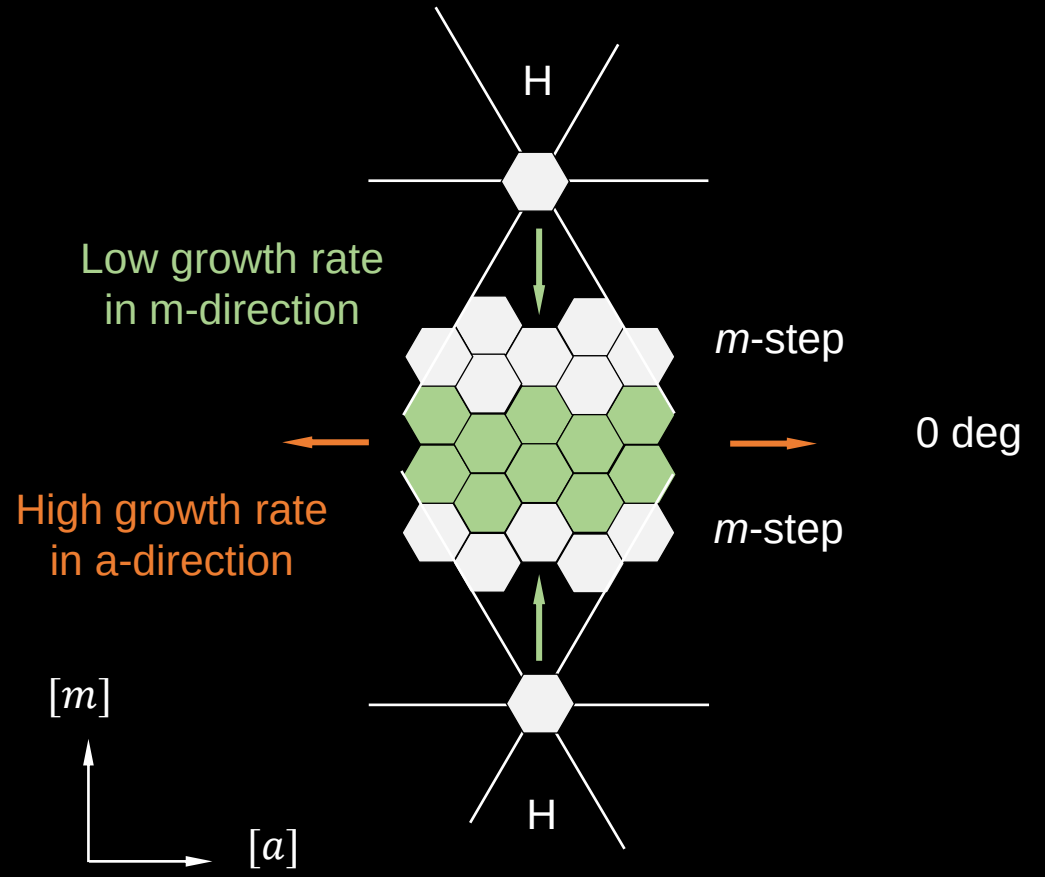


As-grown n-type Am-GaN crystal



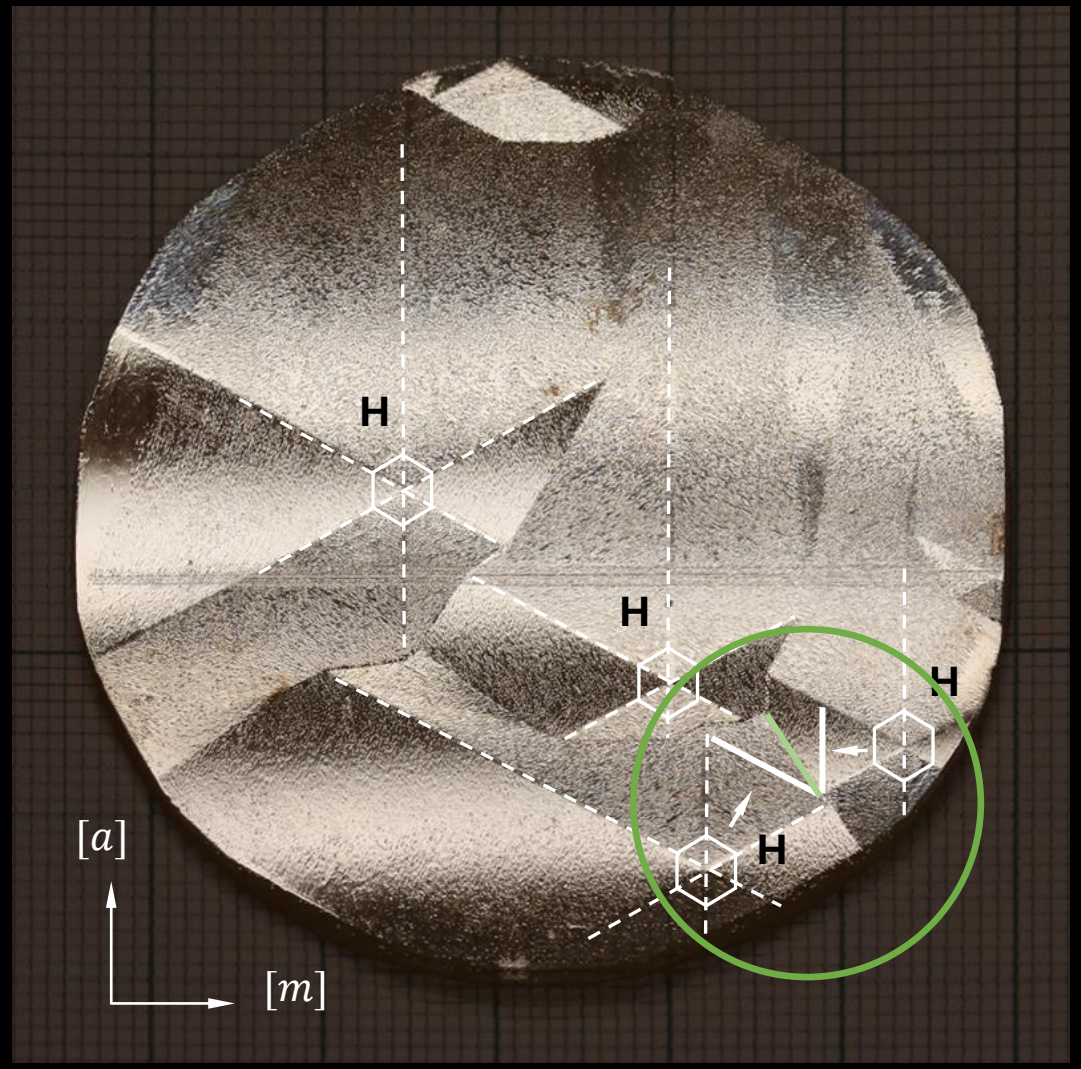
0 deg between steps on adjacent hillocks

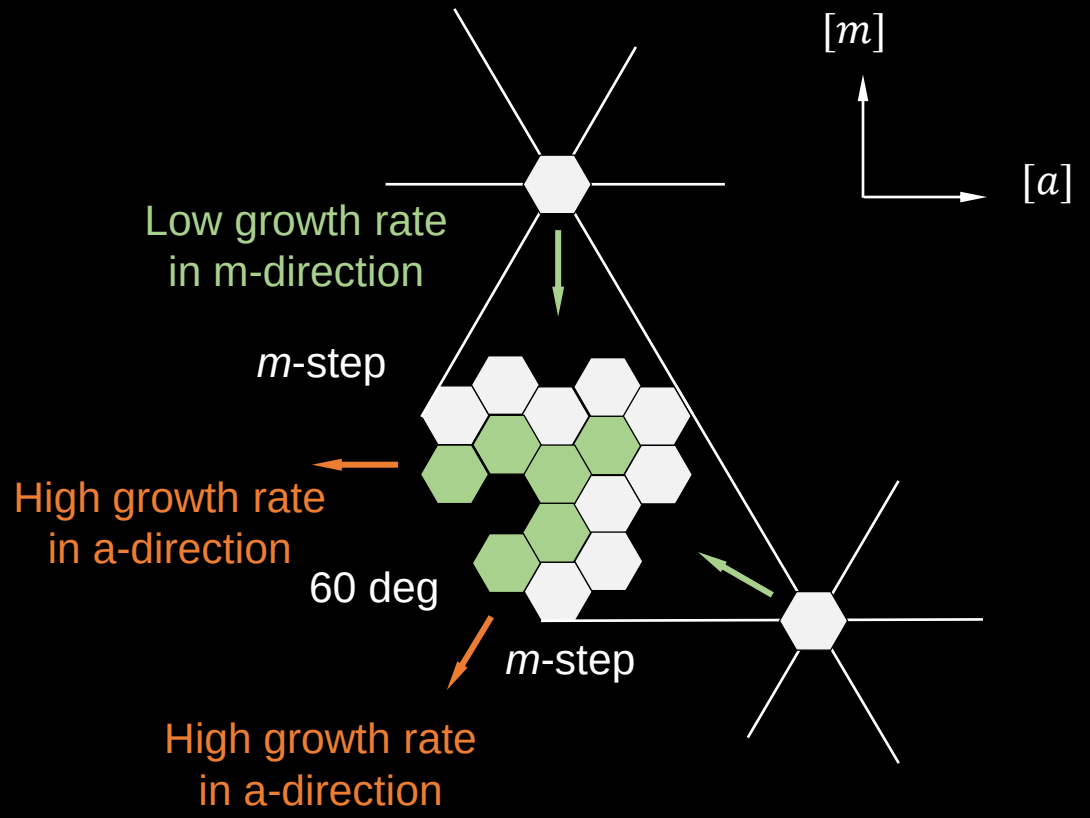




The valley is filled with expanding m-steps

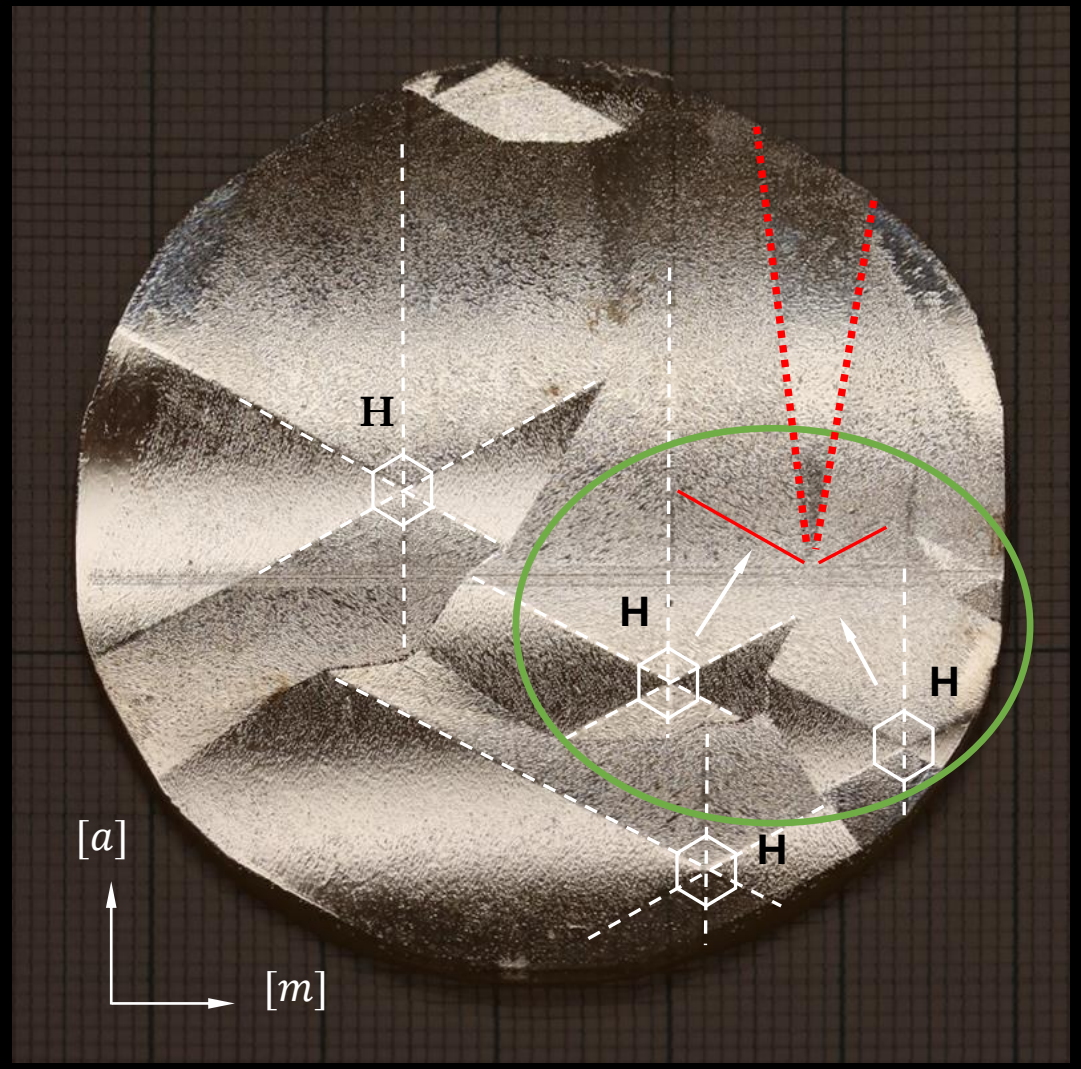
60 deg between steps on adjacent hillocks

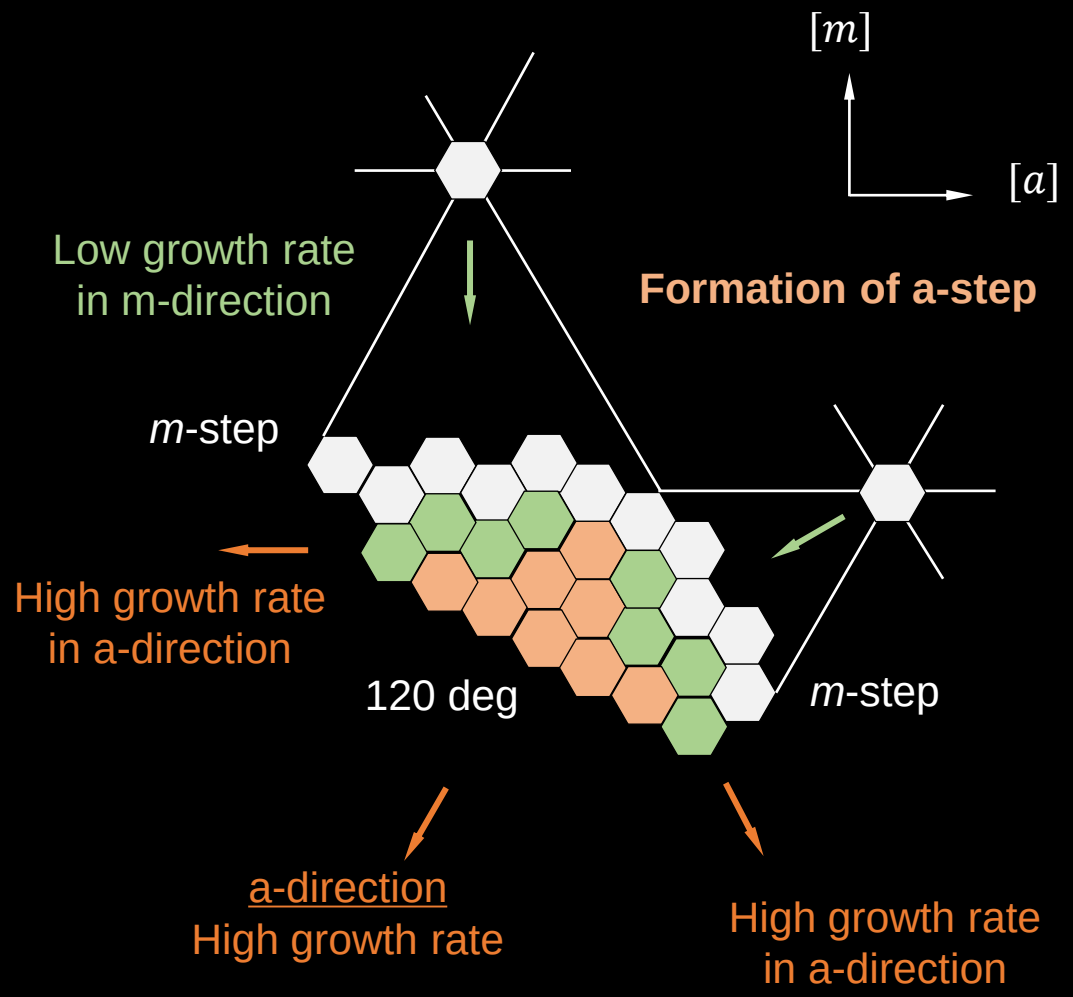




The valley is filled with expanding m-steps

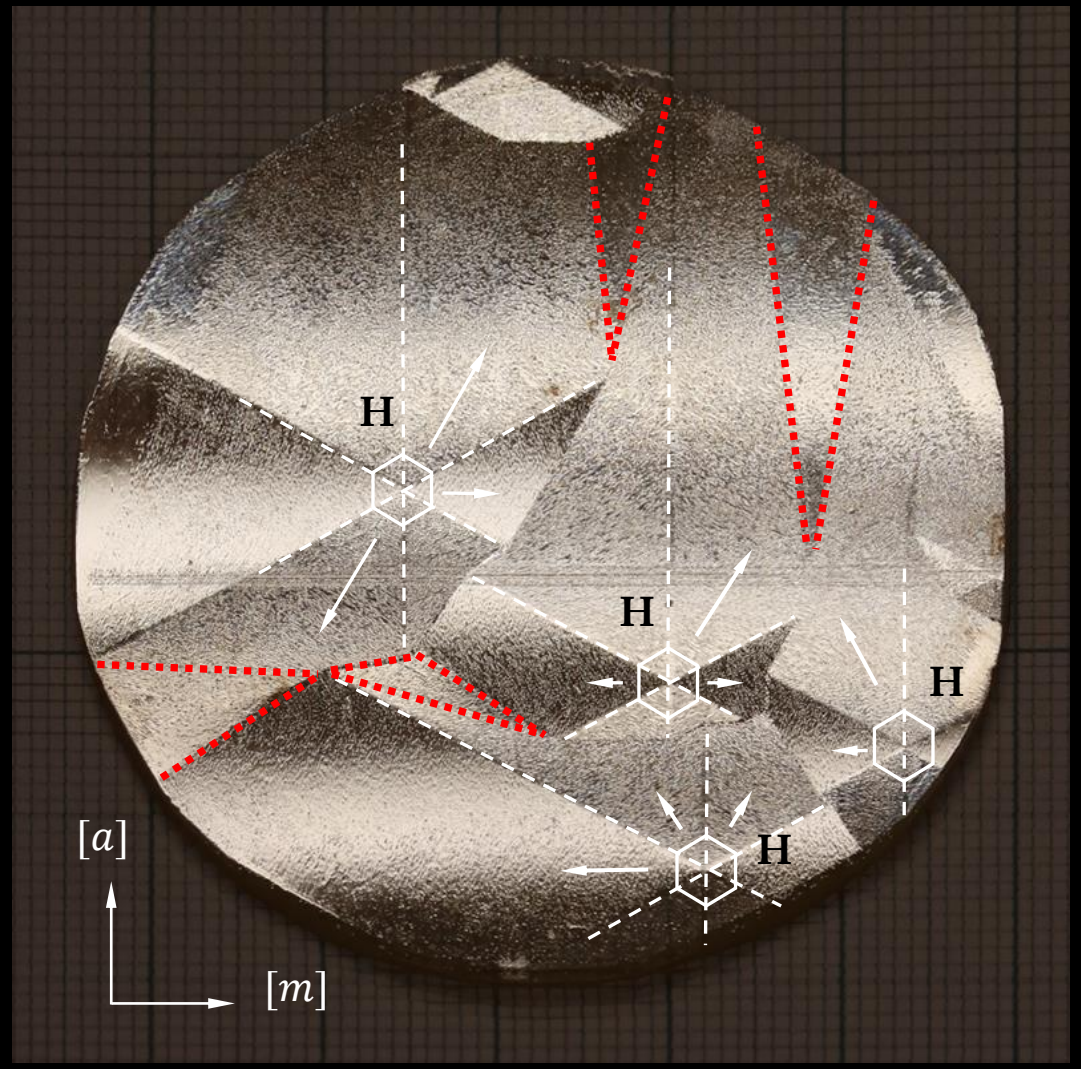
120 deg between steps on adjacent hillocks

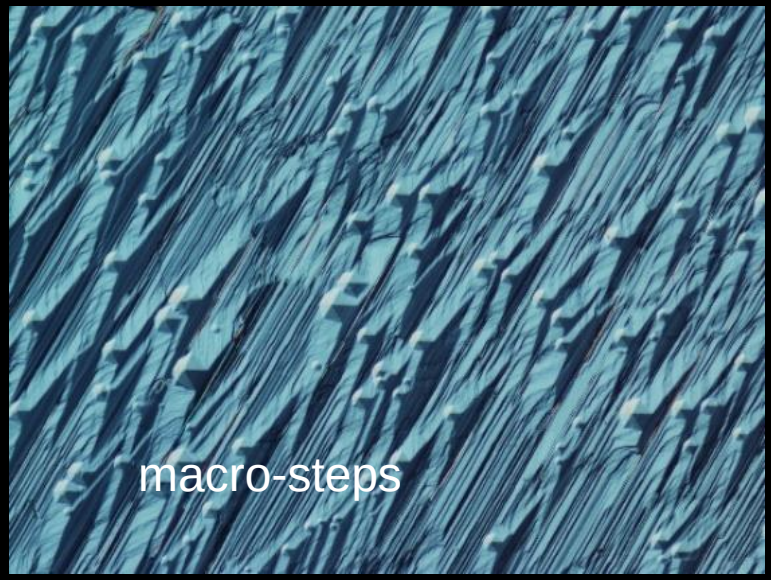


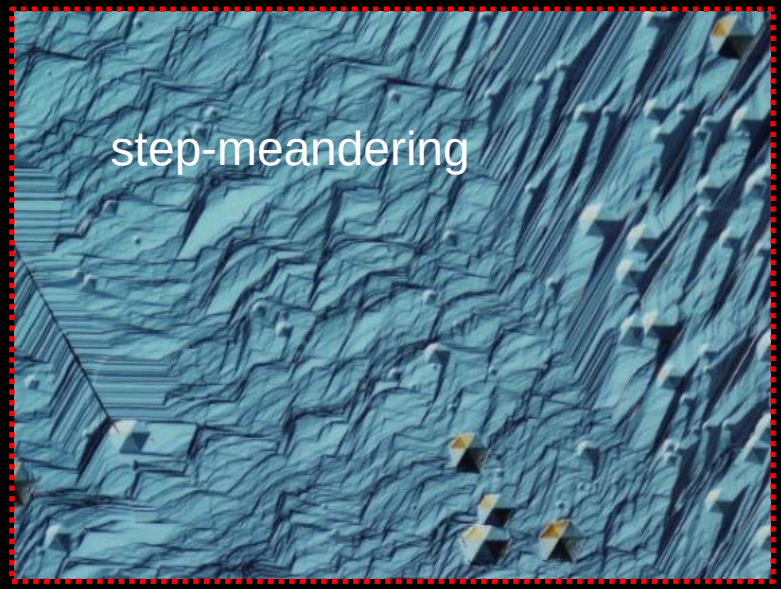


Propagation of a-step is realized with higher rate then m-step

Analysis of the growth morphology

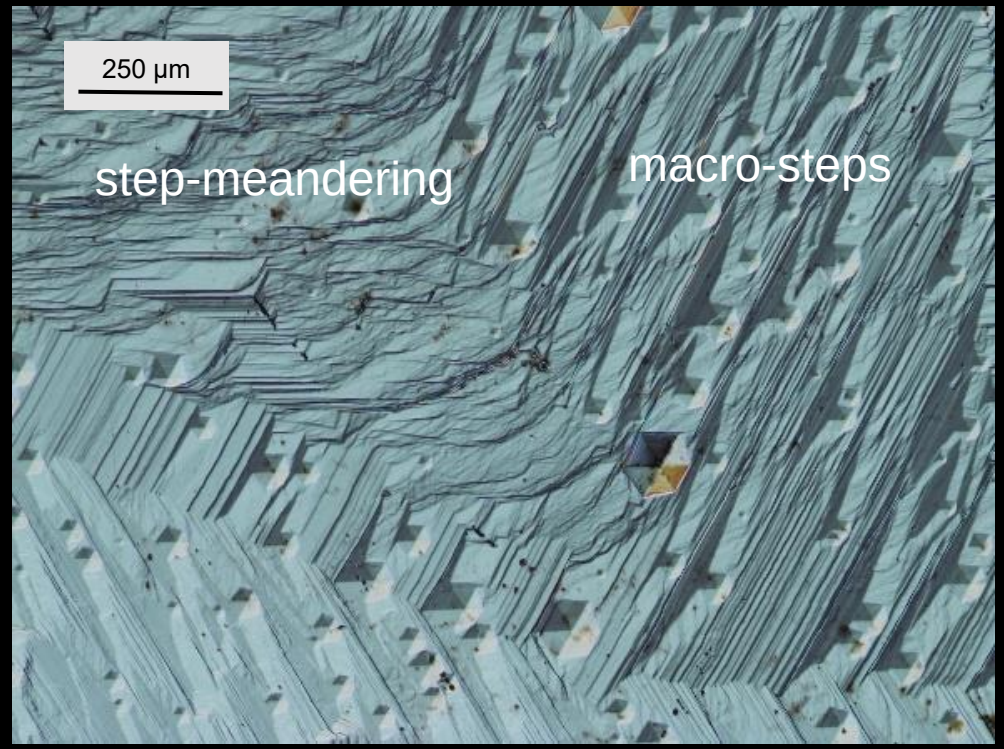




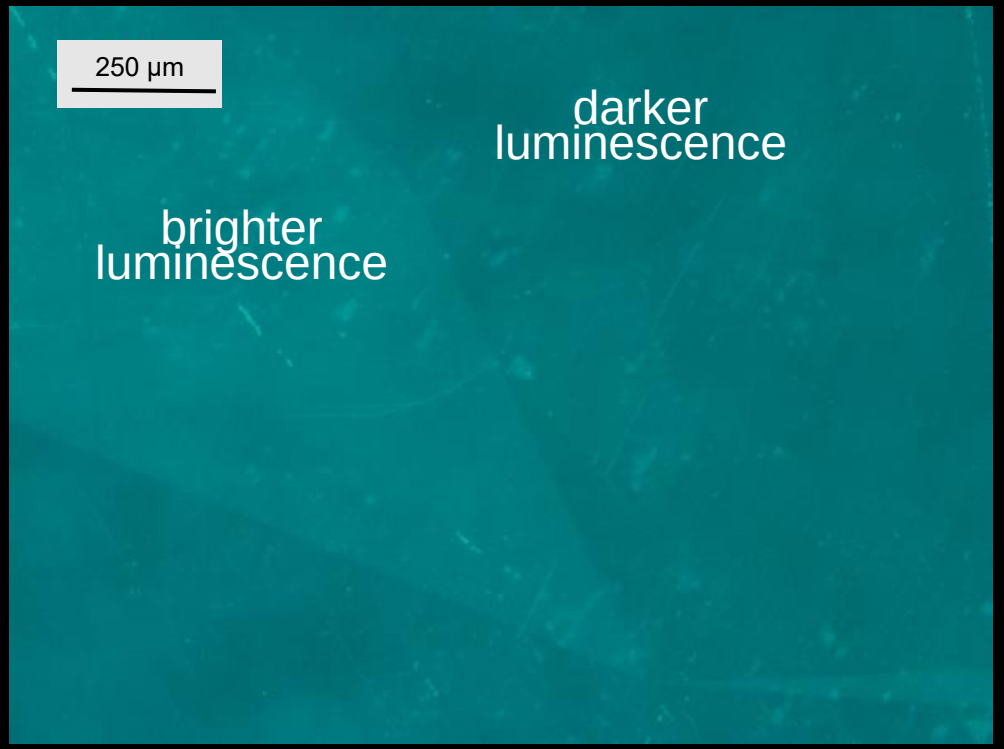


Analysis of the growth morphology

Nomarski contrast



UV illumination

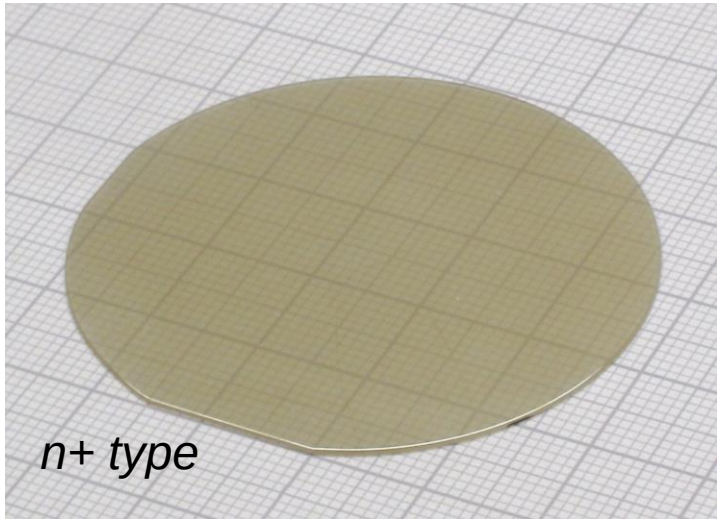


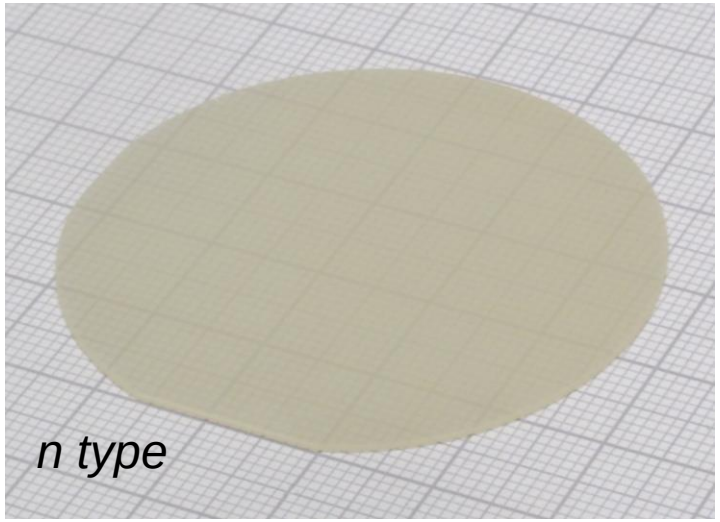
The places where the **macro-steps** are visible correspond to an area of **darker luminescence**.
In turn, areas with **step-meandering** correspond to parts with **brighter luminescence**.

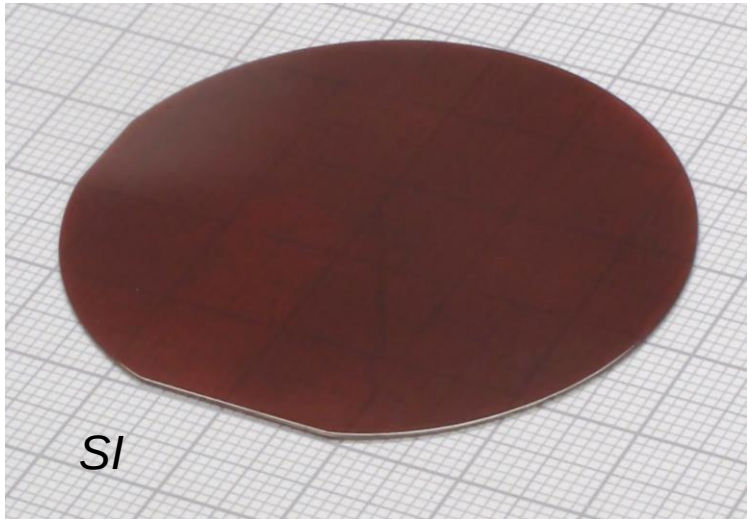
n+ vs n type

Am-GaN

2 inch Am-GaN substrates – electrical properties

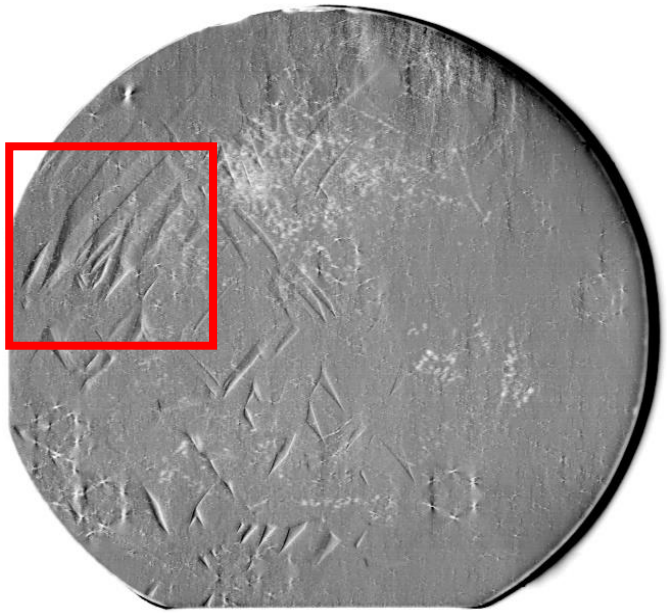






Material type	Conductivity type	Carrier concentration [cm^{-3}]	Carrier mobility [cm^2/Vs]	Resistivity [Ωcm]
High carrier concentration	**n+ type**	**~10^{19}**	~150	10^{-3}
Low carrier concentration	**n type**	**~10^{18}**	~250	10^{-2}
High resistivity (Mn-doped)	**semi-insulating (SI)**	-	-	**≥10^{8}**

n+ Am-GaN substrate



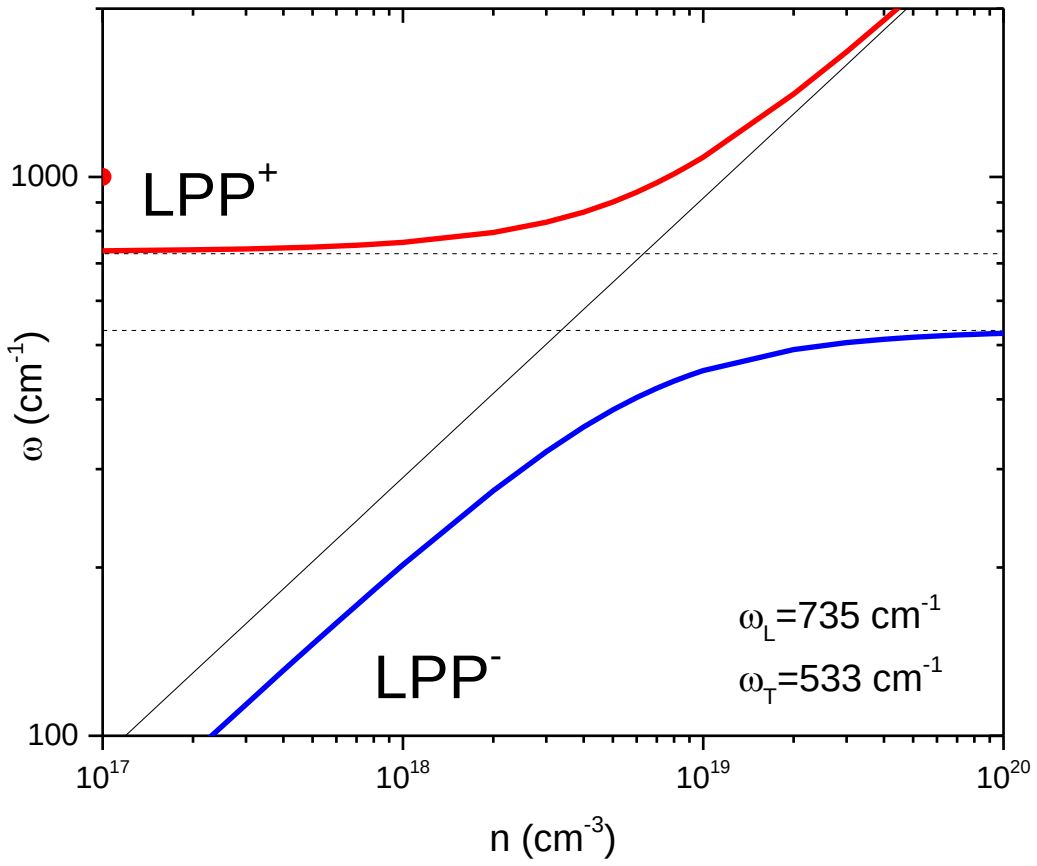
5 mm

$11\bar{2}0$

OM (UV)

The area out of "propellers" region is characterized by a higher free carriers concentration.

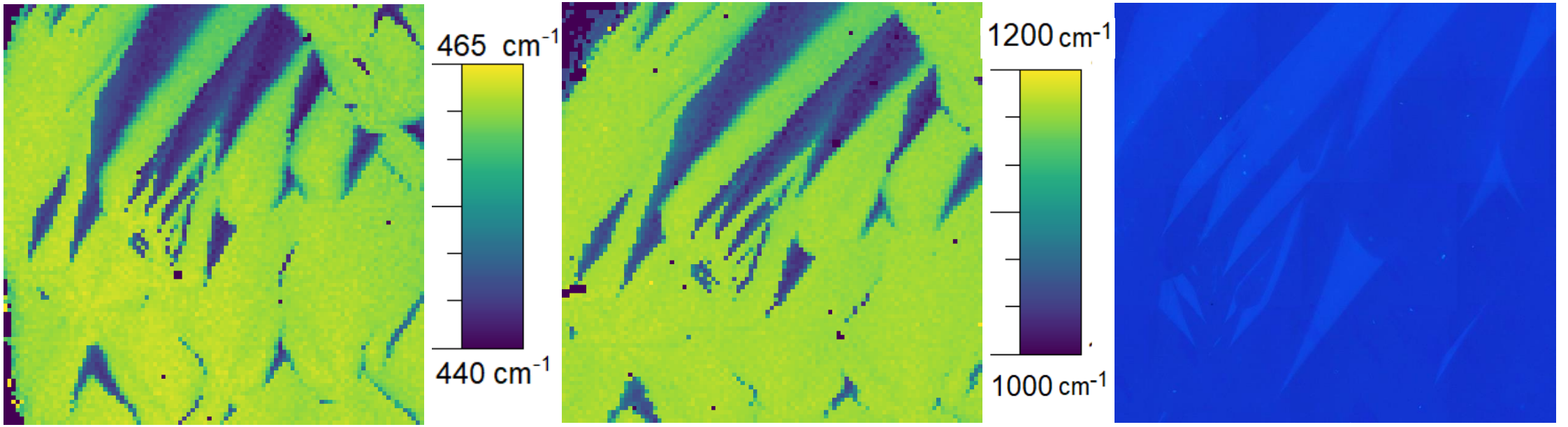
Raman measurments



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

LPP- , LPP+ Raman signature

Raman shift LPP-



Raman shift LPP+

OM (UV)

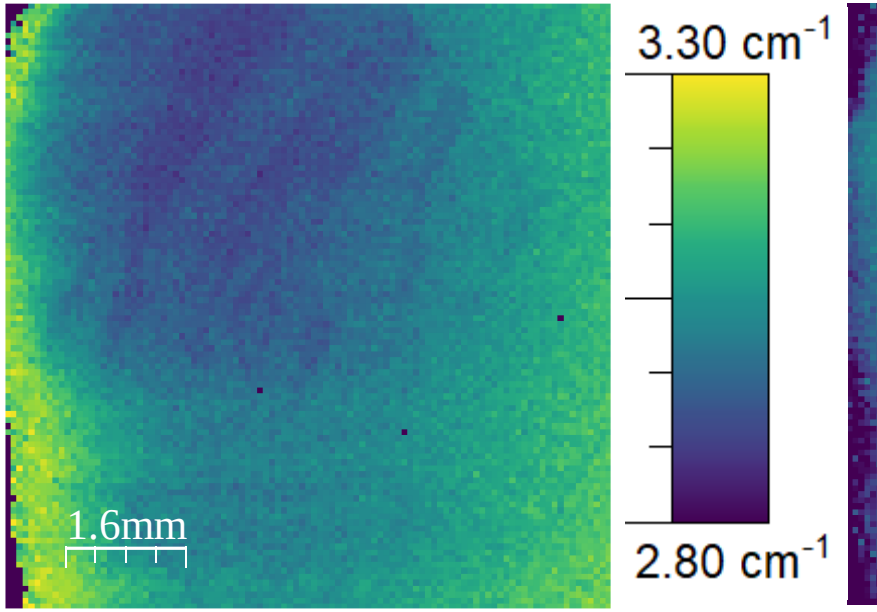
n+ Am-GaN

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

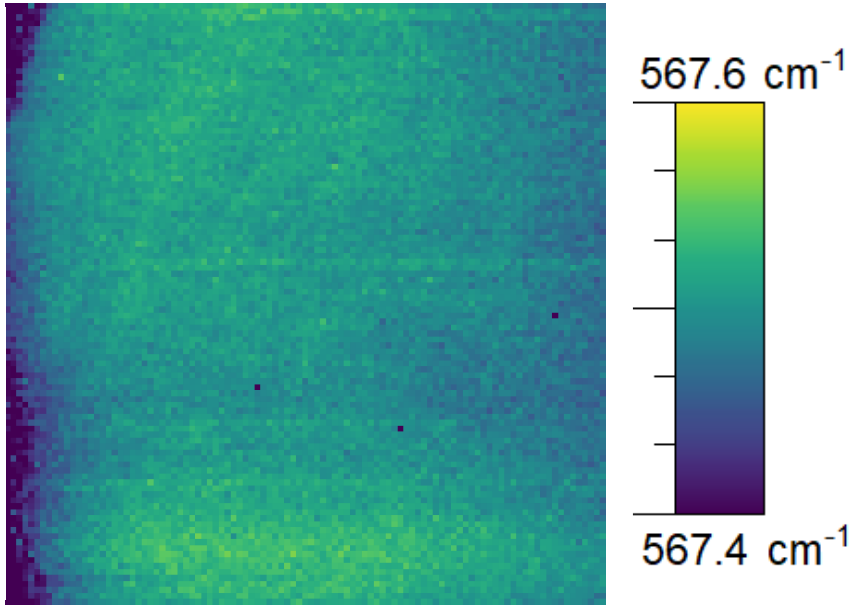
E_2 Raman signature vs XRT transmission

XRT transmission

FWHM E_2

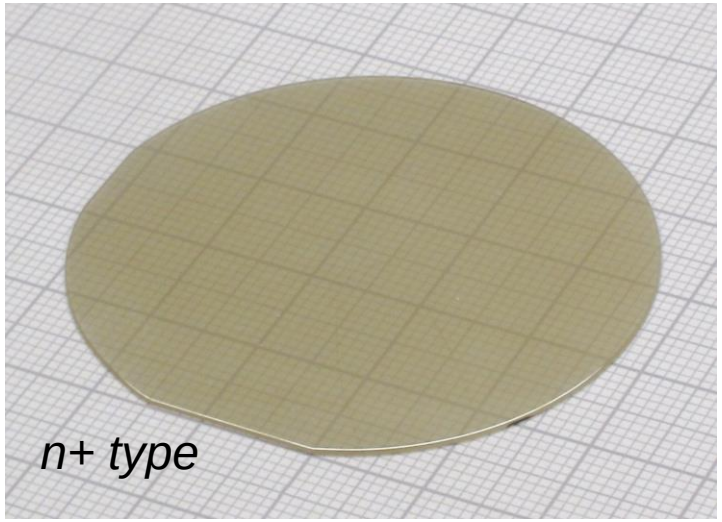


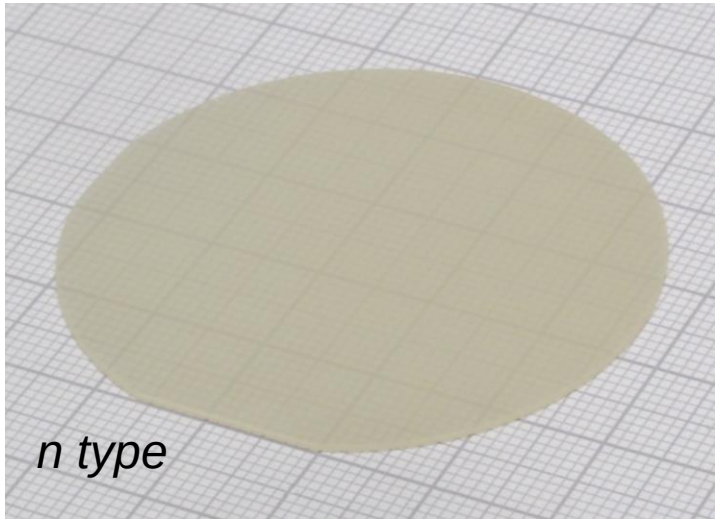
Raman shift E_2

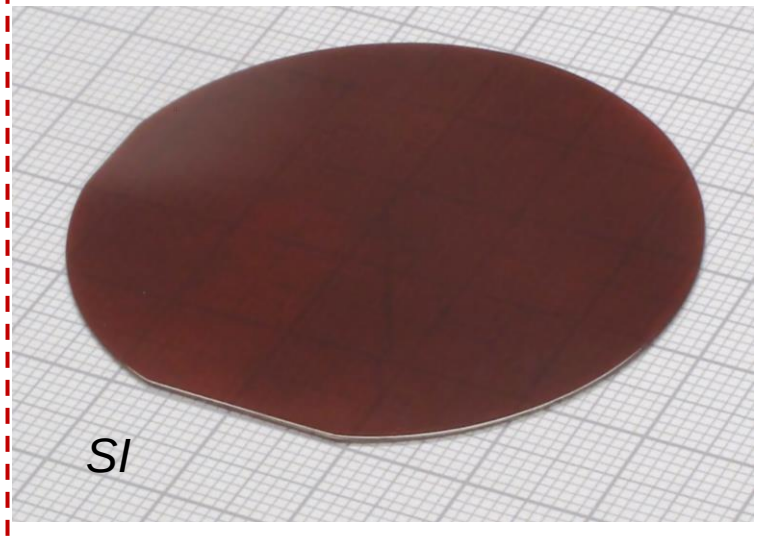


The area inside of "propellers" region is characterized by a lower free carriers concentration.

2 inch Am-GaN substrates – electrical properties

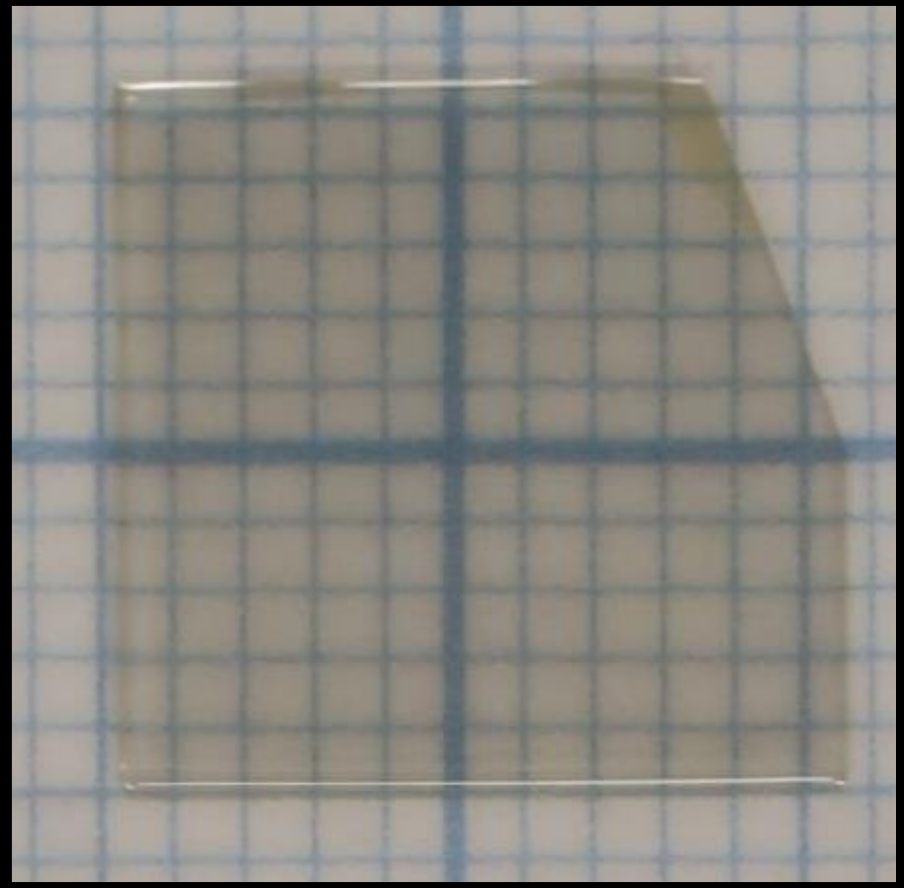


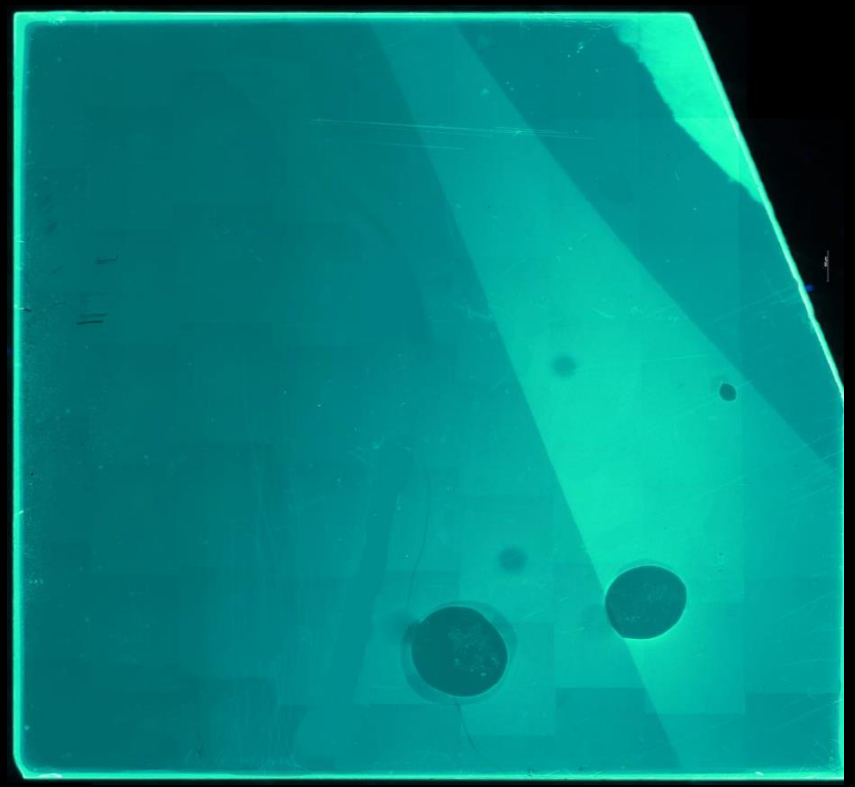




Material type	Conductivity type	Carrier concentration [cm^{-3}]	Carrier mobility [cm^2/Vs]	Resistivity [Ωcm]
High carrier concentration	**n+ type**	**~10^{19}**	~150	10^{-3}
Low carrier concentration	**n type**	**~10^{18}**	~250	10^{-2}
High resistivity (Mn-doped)	**semi-insulating (SI)**	-	-	**≥10^{8}**

n - Am-GaN substrate



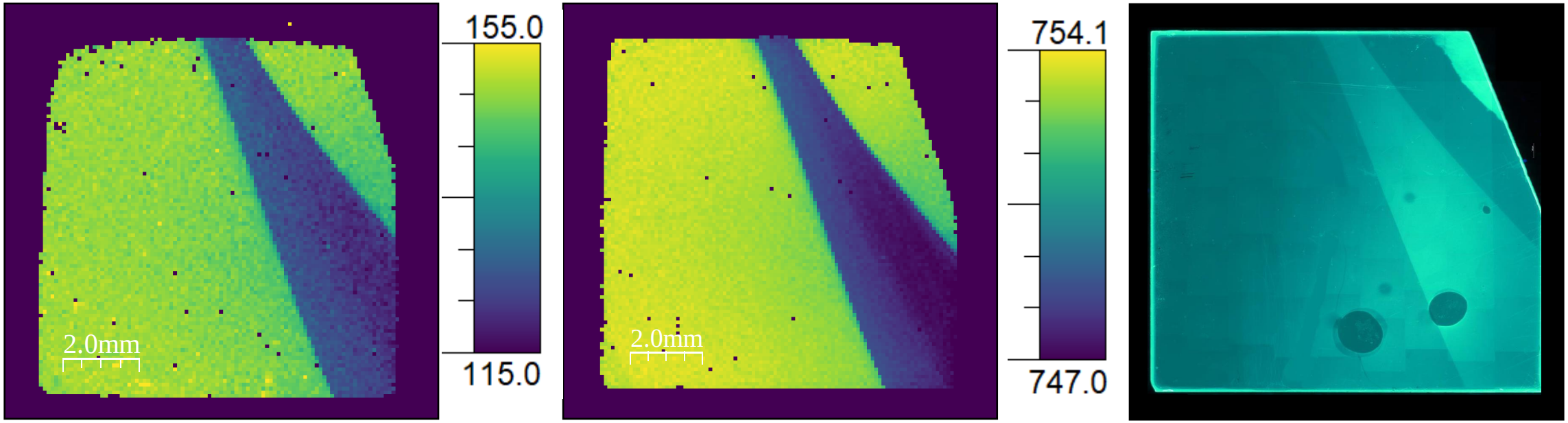


LPP- , LPP+ Raman signature

Raman shift LPP-

Raman shift LPP+

OM (UV)



n Am-GaN

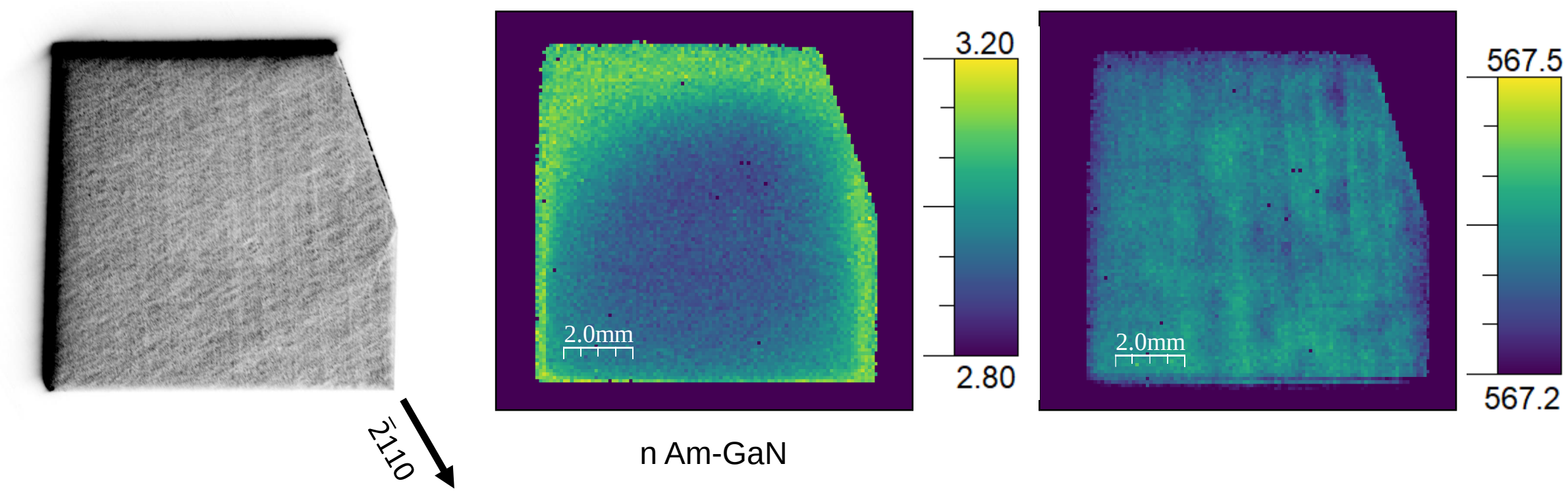
The area inside of "propellers" region is characterized by a lower free carriers concentration.

LPP-, LPP+ and E_2 Raman signature

XRT transmission

FWHM E_2

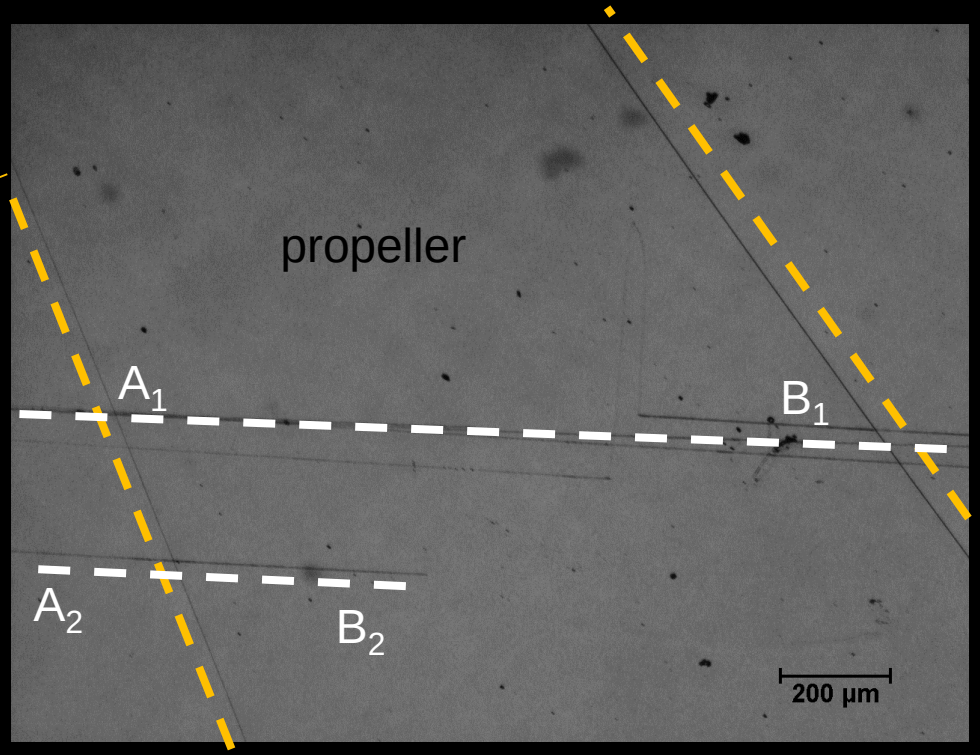
Raman shift E_2



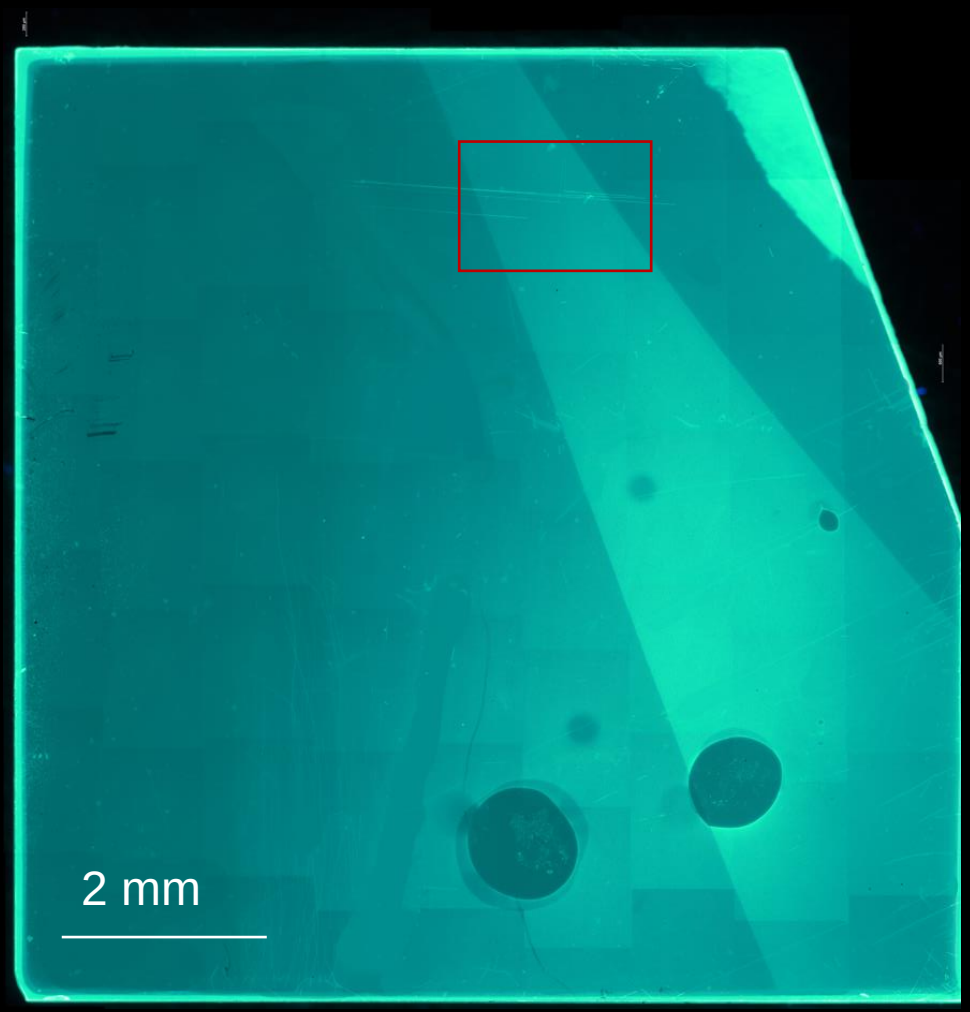
The area inside of "propellers" region is characterized by a lower free carriers concentration.
No effects of strain/stress related to the presence of "propellers" are visible.

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

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

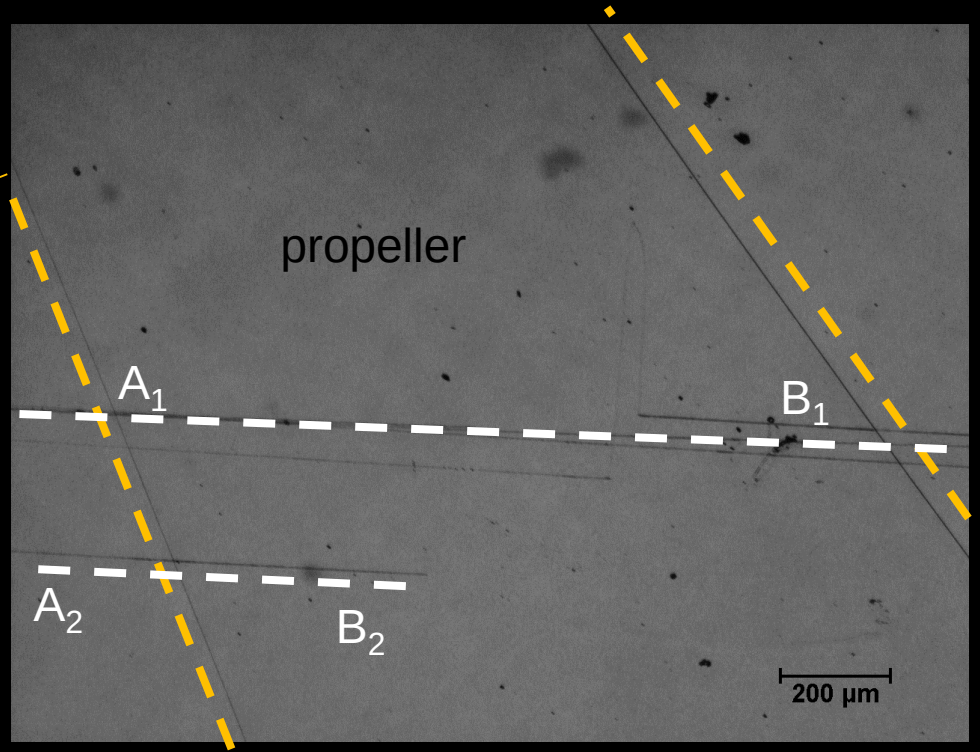


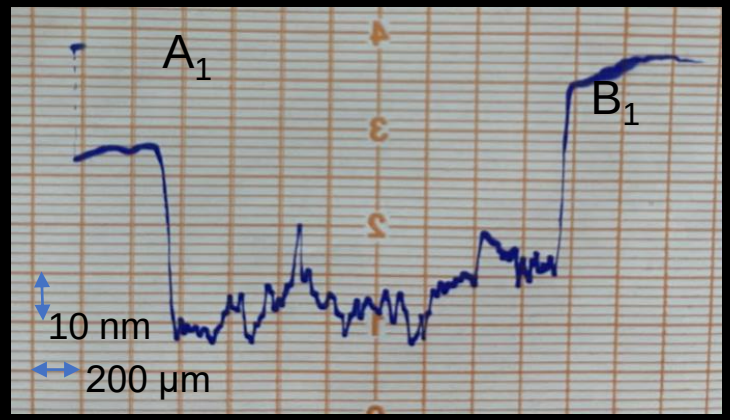
DIC image of the sample surface after PE

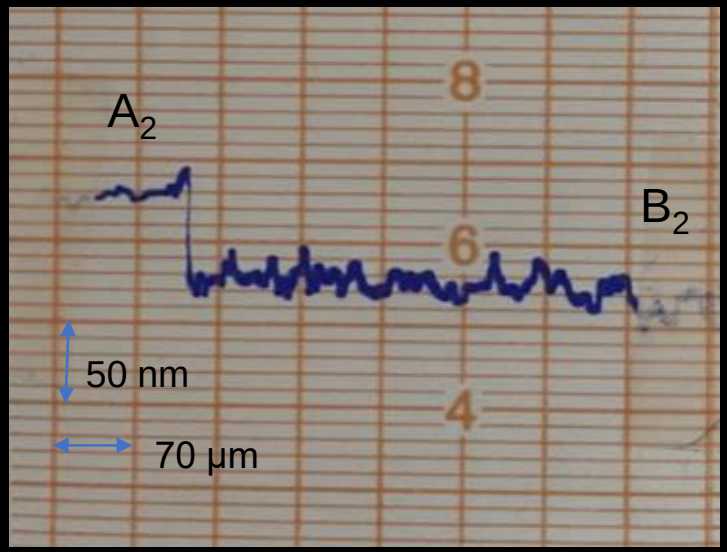


UV map of the Am-GaN sample

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







DIC image of the sample surface after PE

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-meandring);
- Occurrence of step-meandring 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+ Am-GaN substrates.

Acknowledgments

This research was supported by the The National Centre for Research and Development

through project LIDER14/0152/2023

Thank you for your attention