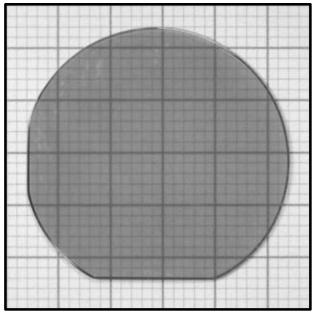
HVPE-GaN growth on ammonothermal GaN seeds:

State of the art

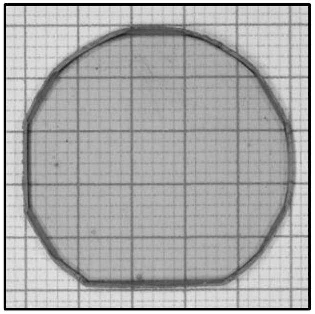
INFLUENCE OF SEED MISORIENTATION

Growth rate vs Critical Thickness

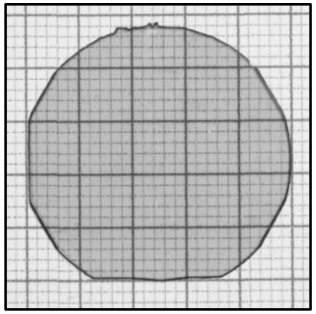
HVPE-GaN on Ammono-GaN



Growth



Slicing

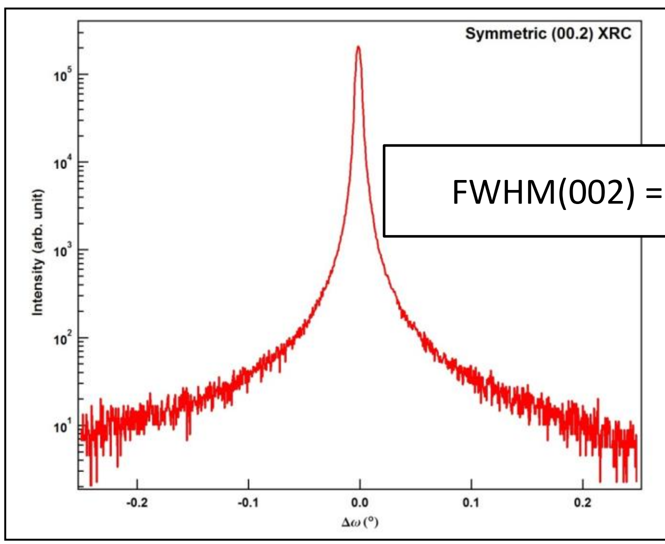


Am-GaN

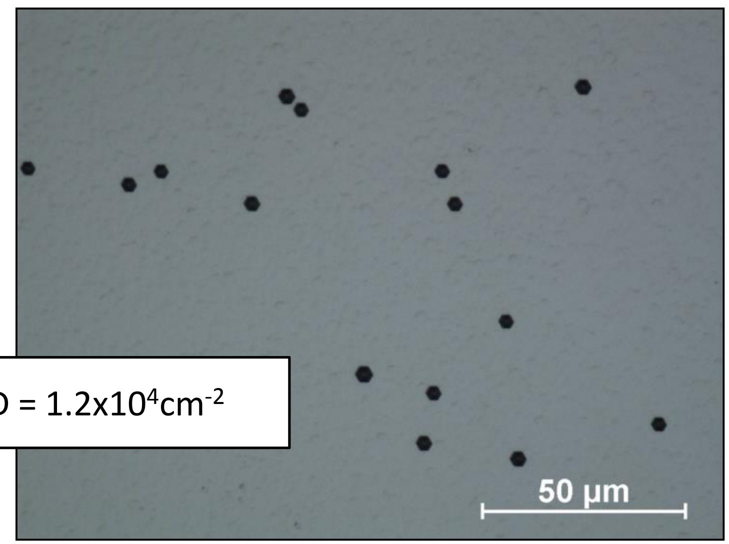
HVPE-GaN / Am-GaN

F-S HVPE GaN

<u>Seed misorientation: 0.3° to m direction</u>

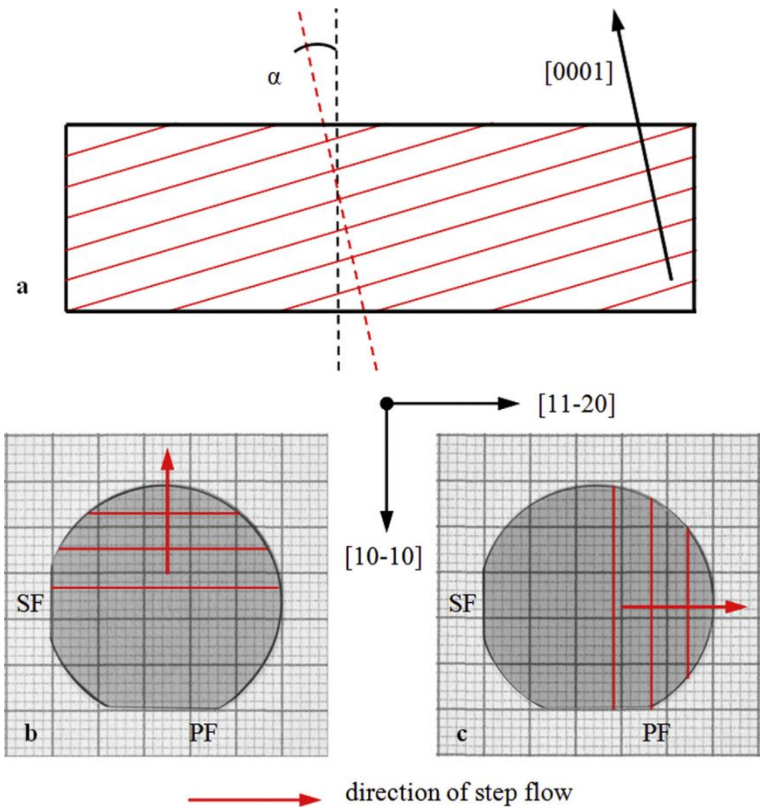


FWHM(002) = 19”



TDD = $1.2x10^4 cm^{-2}$

Misorientation



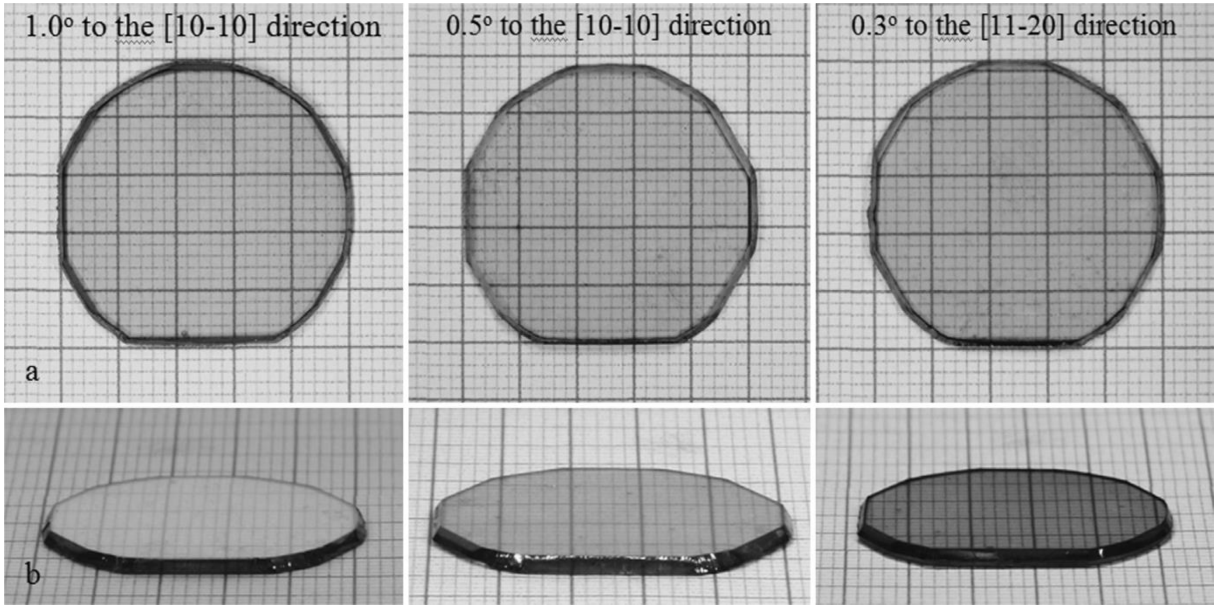
Schematic illustrations of Am-GaN seed misorientation: a) cross-section of the seed; red lines represent crystallographic planes; black lines represent the seed's surfaces; α is defined as an angle of misorientation; b) (0001) plane of the seed misoriented to the [10-10] direction c) (0001) plane of the seed misoriented to the [11-20] direction; primary flat (PF) and secondary flat (SF) are marked; directions of step flow, induced by the appropriate misorientation, are visualized.

Misorientation of the seeds used in experiments:

$\alpha = 0.3^o$, $\alpha = 0.5^o$, $\alpha = 1.0^o$

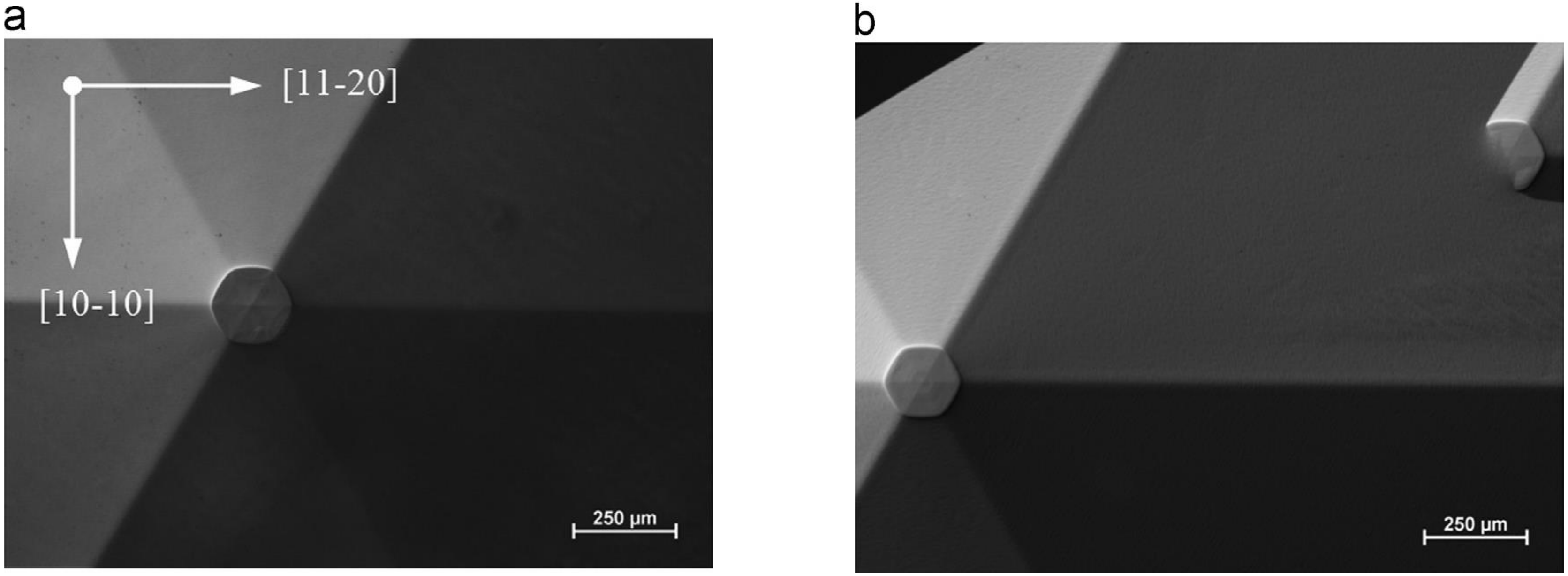
to the **„m" <10-10>** and **„a" <11-20>** directions

1-mm-thick HVPE-GaN layers grown on 400-µm-thick 1-inch Am-GaN seeds



1-mm-thick HVPE-GaN crystals grown on 400-µm-thick 1-inch Am-GaN seeds with various misorientations (0.3, 0.5, and 1 degree) to the [10-10] and/or to the [11-20] direction: a) top view, b) bird's-eye view; grid 1 mm.

Growth Morphology after eight hours of the growth

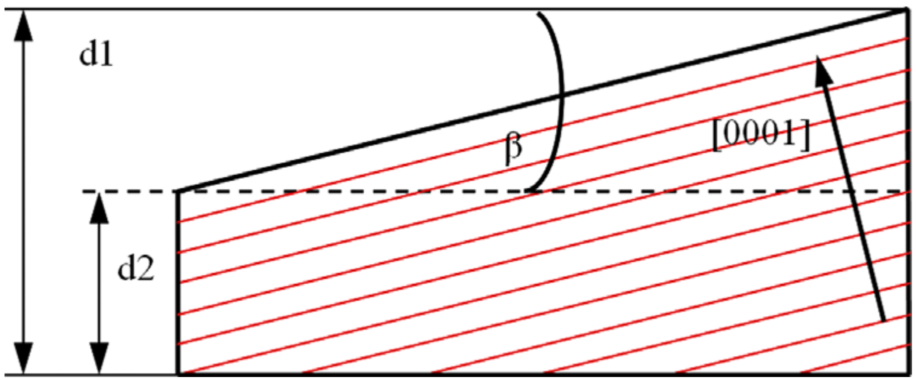


HVPE-GaN surface morphology after eight hours of the growth on seeds misoriented to the „a" and „m" directions a) typical hillock; b) two hillocks with one of them being "consumed" by the second one.

Average growth rate: **130-150µm/h**

Difference in crystal thickness

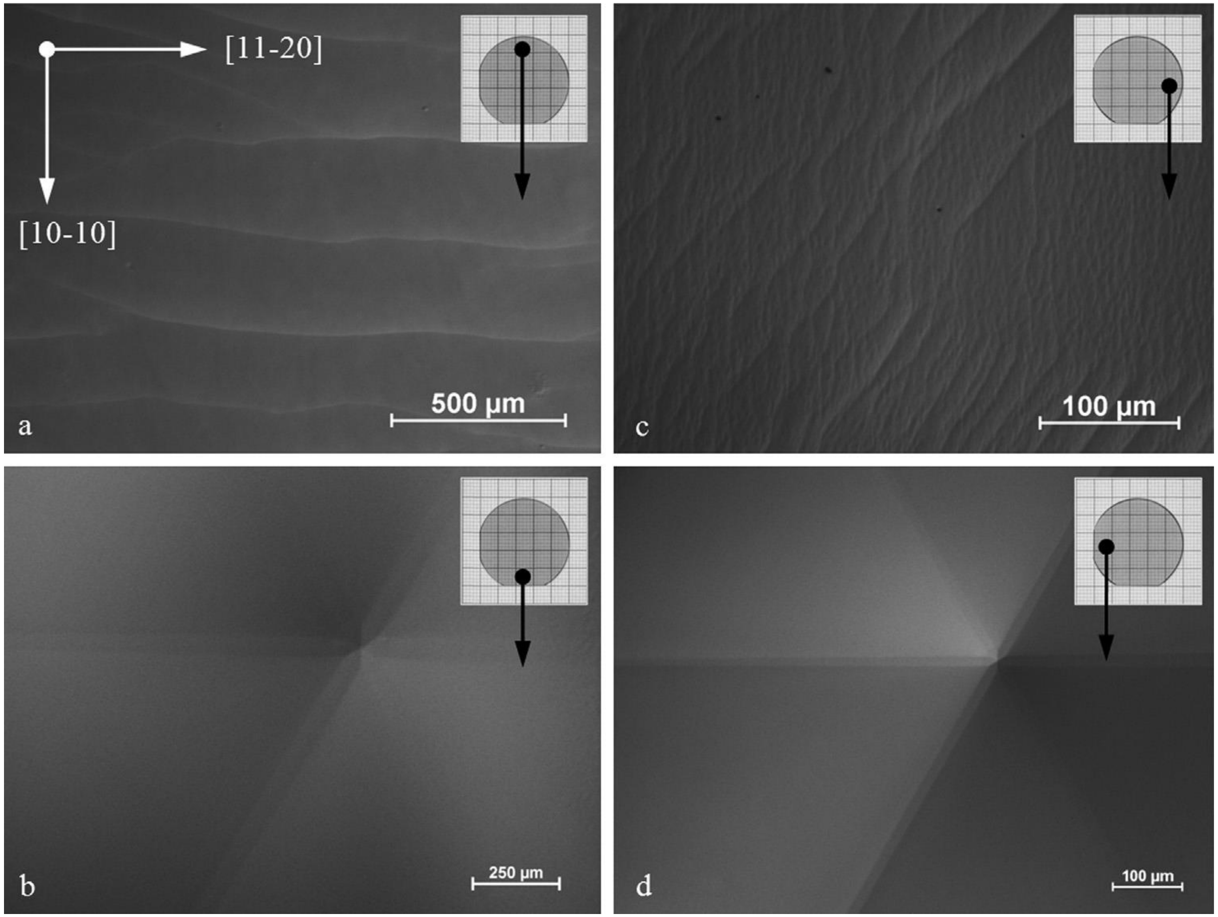
Macroscopic observation of all the grown samples (in particular on Am-GaN seeds misoriented 0.5 and 1 degree to the examined directions) showed their wedge shape.



Schematic view of a wedge shape of a grown sample; d1,d2 represent the thickness of HVPE-GaN grown on an Am-GaN seed measured on two sides of the crystal along the direction of the seed's misorientation; for Am-GaN seeds misoriented 0.5 degree to the examined directions the measured difference in thickness (d1–d2) was equal to200 μm; for Am-GaN seeds misoriented 1 degree to the examined directions, the measured difference in thickness (d1–d2) was equal to 400 μm; β represents an angle between a misoriented seed's surface and a surface formed after the growth process.

Growth Morphology after short-time growth

Macrosteps propagation was observed on the entire 1-in. crystal's surface after one-hour-long experiments. It was detected for all examined misorientations.



Two types of morphologies were observed on the surface after two hours of growth on the seed misoriented 1degree to the [10-10] and [11-20] directions; (a) macrosteps propagation to the [1010] direction; (b) hillock formation on the HVPE-GaN layer grown on the misoriented to the [10-10] direction Am-GaN seed; (c) macrosteps propagation to the [11-20] direction; (d) hillock formation on the HVPE-GaN layer grown on the misoriented to the [11-20] direction Am-GaN seed; all presented areas are marked on additional Am-GaN seeds images.

Average growth rate, determined by a comparison of the seeds' weight before and after one- and two-hour experiments, was of the order of 60 µm/h.

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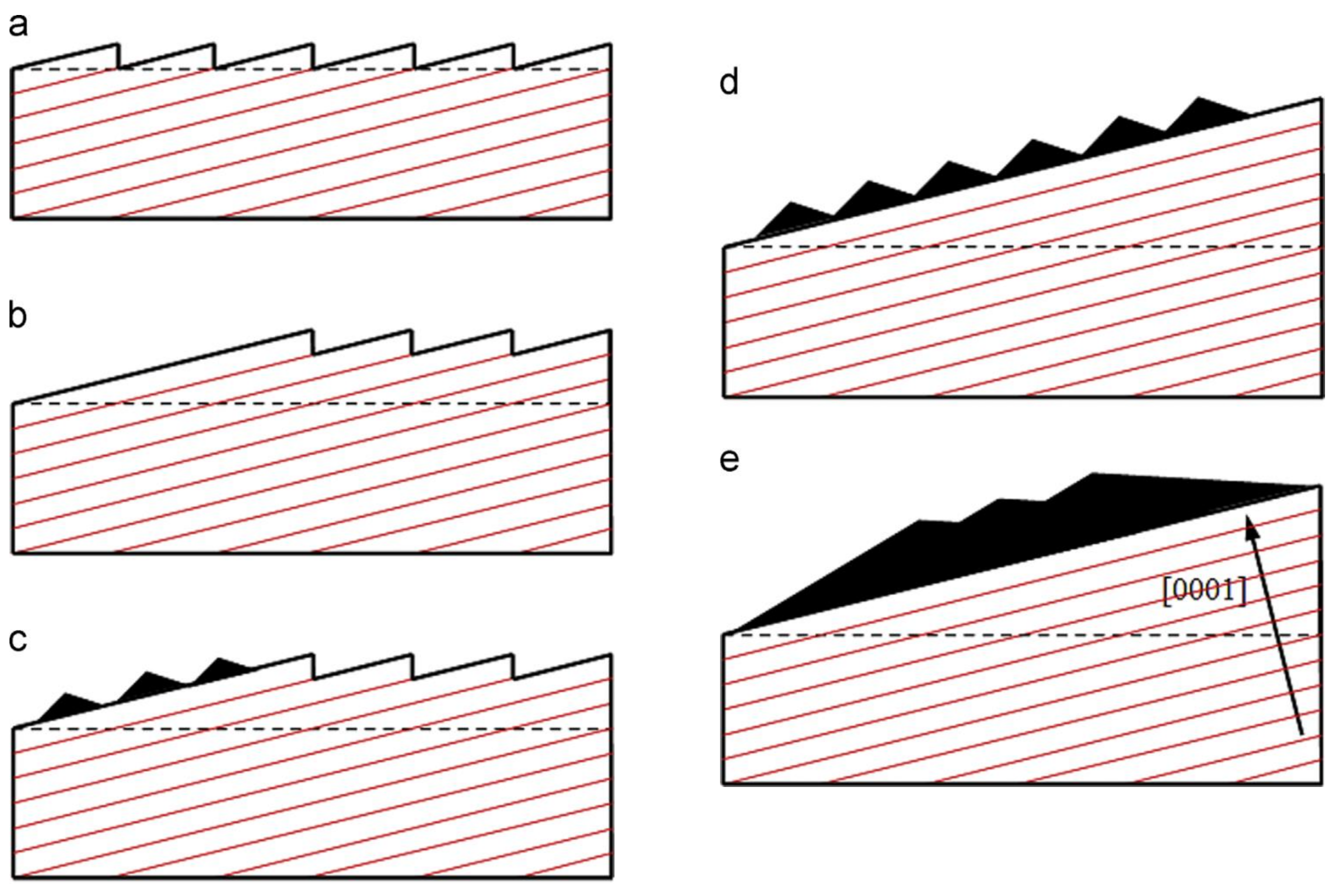
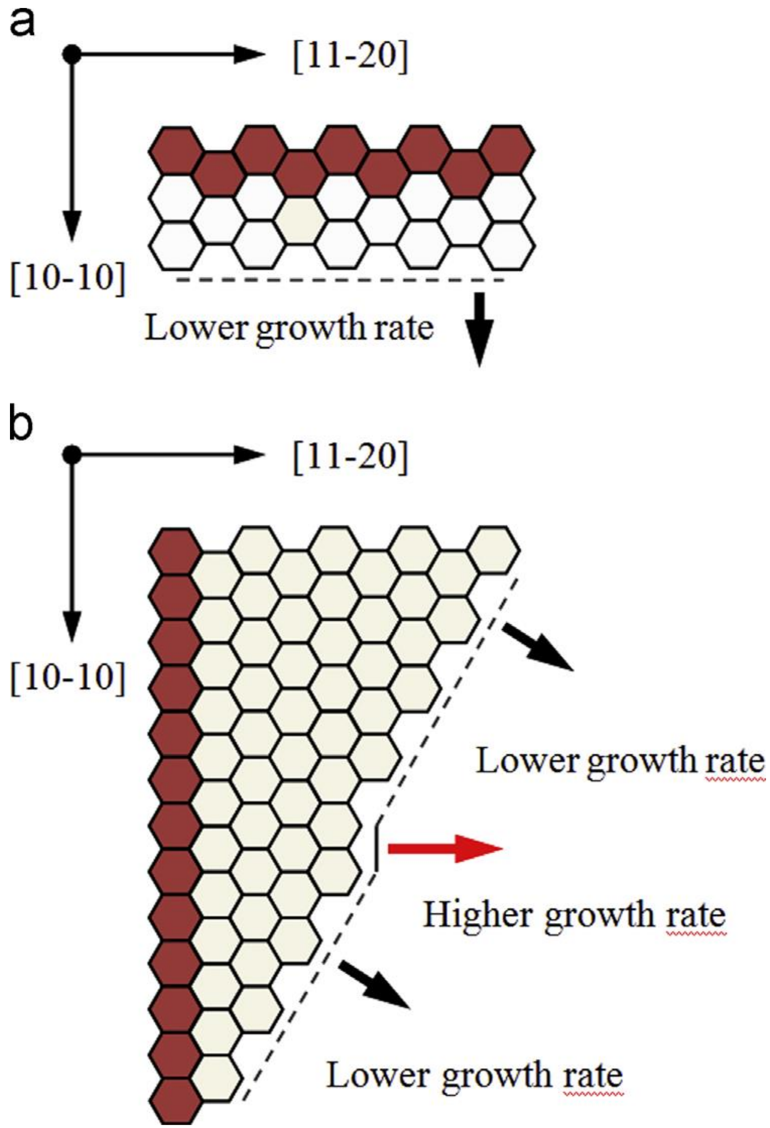
Model of growth on misoriented seeds



Model of growth on misoriented Am-GaN seeds: a) macrostep flow, b) start of the c-plane recovery; c) start of hillocks growth on the recovered c-plane, d) hillocks growth on the entire crystal surface; e) hillocks consuming one another.

Model of macrosteps propagation on an Am-GaN seed misoriented to the a) [10-10] direction; b) [11-20] direction.

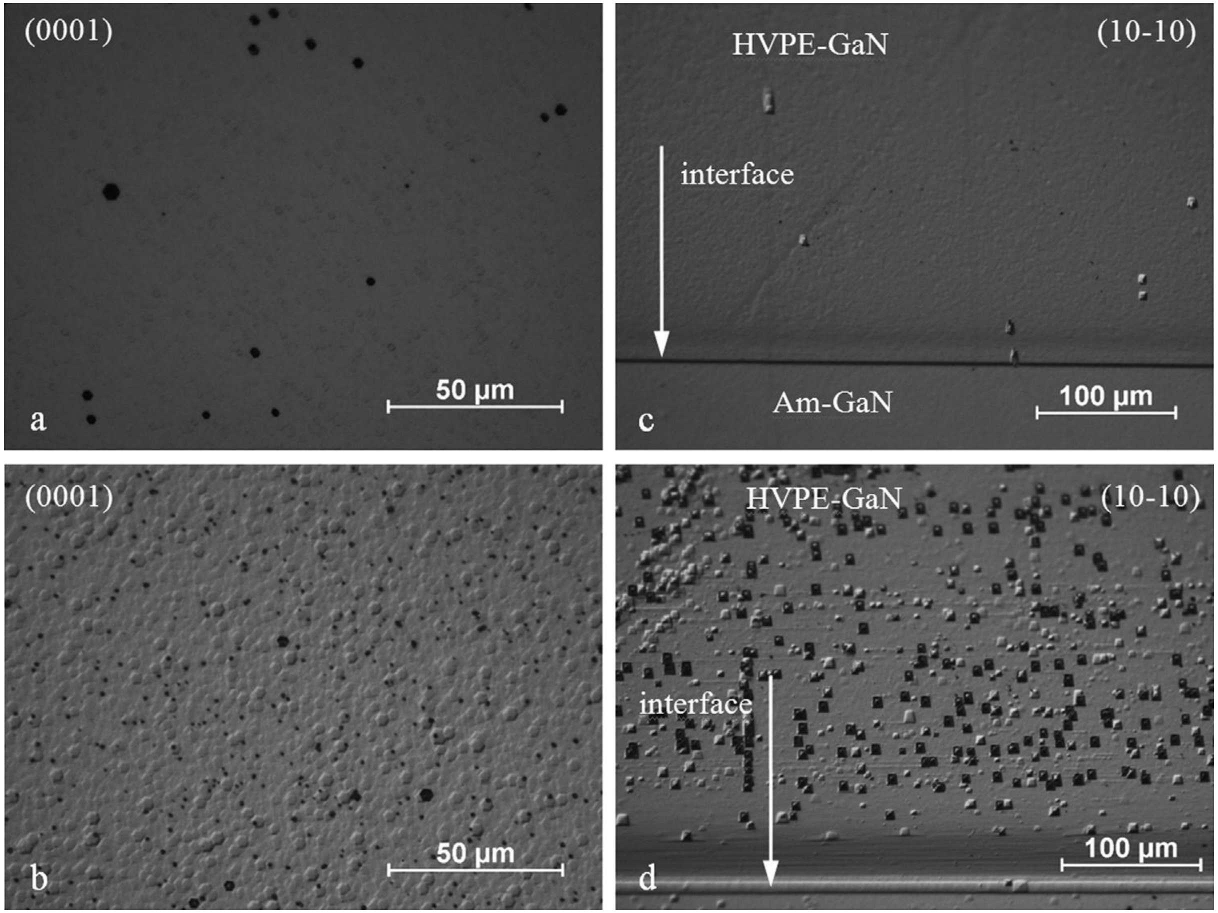


During a crystallization run on a seed misoriented to the [10-10] direction, macrosteps were reconstructed by a relatively fast growth in the [11-20] direction. In Fig. a it is represented by a few lines extending in the [11-20] direction. These lines correspond to edges of the macrosteps. During a crystallization run on a seed misoriented to the [11-20] direction a zigzag shape of macrosteps was observed. It resulted from the fact that the growth rate in the [11-20] direction was higher than in the [10-10]. Thus, the macrosteps were reconstructed here by a slow growth in the [10-10] direction. This happened as a result of the (11-20) facet being a higher-energy facet, thus, the lower-energy facet (10-10) has to be formed due to a natural tendency to its recovery.

DSE of „c” plane and „m” plane cross - section

TDD = $1.2*10^4 cm^{-2}$

TDD = $3*10^6 cm^{-2}$



(a) (0001) surface of HVPE-GaN grown on an Am-GaN seed misoriented 1 degree to the [1010] direction after a DSE process;
(b) (0001) surface of HVPE-GaN grown on an Am-GaN seed misoriented 1degree to the [1120] direction after a DSE process;
(c) cross section (m-plane) after PEC and DSE procedures of a the sample grown on an Am-GaN seed misoriented 1degree to the [1010] direction;
(d) cross section (m-plane) after PEC and DSE procedures of a sample grown on an Am-GaN seed misoriented 1 degree to the [1120] direction.

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Structural quality - XRD measurements

	FWHM $_{(002)}$ [arcsec]	
Seed misorientation	Seed misoriented to the [10-10] direction	Seed misoriented to the [11-20] direction
0.3°	47	47
0.5°	40	39
1.0°	32	35

beam size 1x10mm^2

FWHMs of X-ray rocking curves were measured for as-grown 1-mm-thick HVPE-GaN layers on Am-GaN seeds of all examined misorientations. The narrowest rocking curve was obtained for HVPE-GaN grown on an Am-GaN seed misoriented 1 degree to the [10-10] and [11-20] directions. Bowing radii of the HVPE-GaN layers showed no change compared to the Am-GaN seeds.

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Summary

1. Structural quality of HVPE-GaN crystals grown on misoriented seeds increases with the angle of misorientation (narrower rocking curves);
2. Dislocation density increases for growth on seeds misoriented to the „a” direction;
3. Growth mode changes during the first stages of the process (from step flow to hillocks);
4. For crystals grown on misoriented seeds the misorientation is lost;
5. Higher growth rate is detected for hillock growth mode than for macrostep mode.