

Molecular beam epitaxy of III-V semiconductors on group-IV substrates: **Formation and burying of antiphase domains.**

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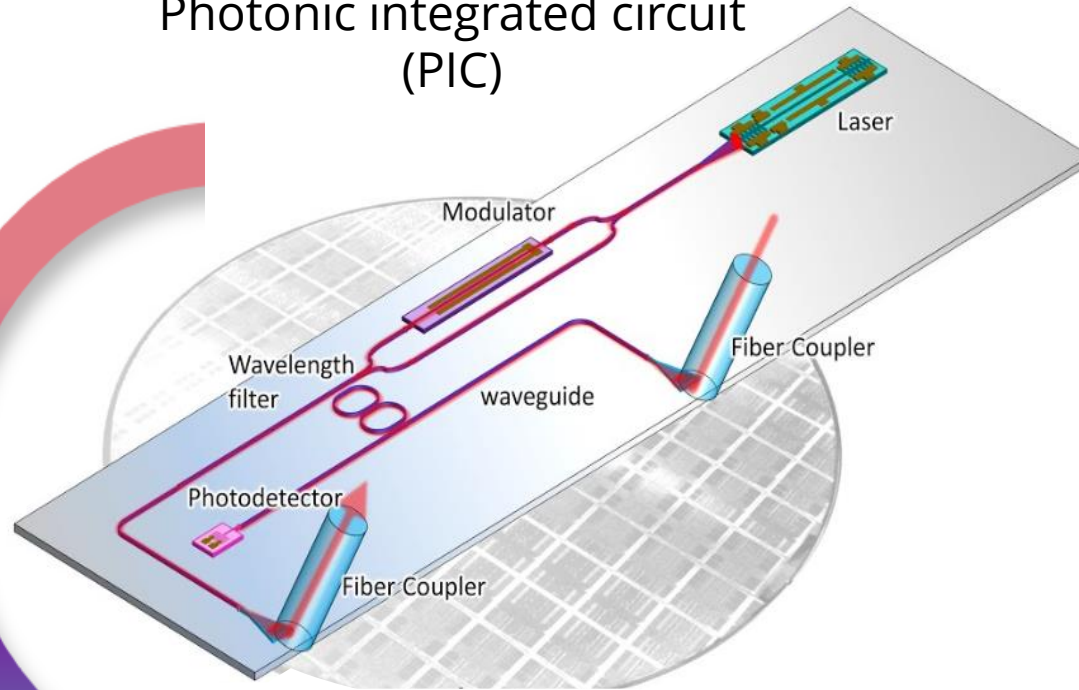
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Motivations

Photonic integrated circuit (PIC)

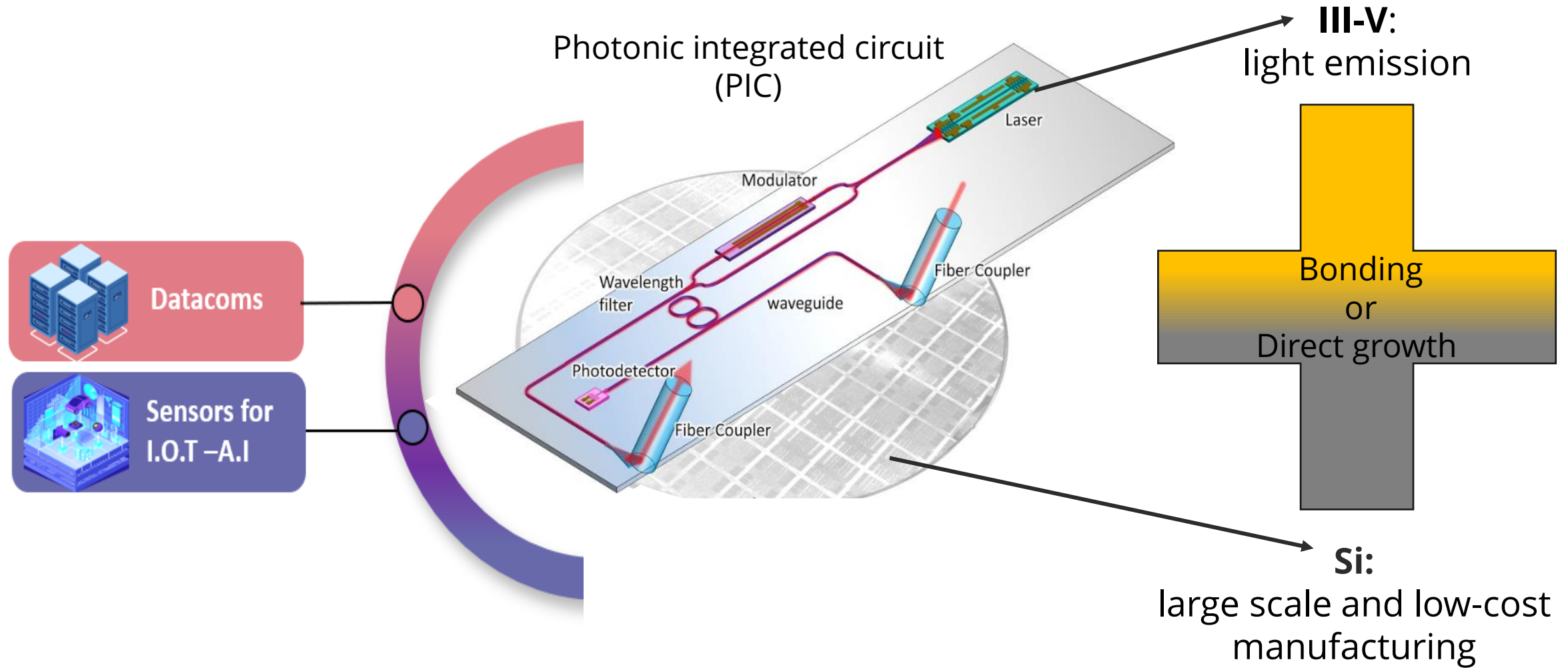


Datacoms



Sensors for I.O.T -A.I

Motivations

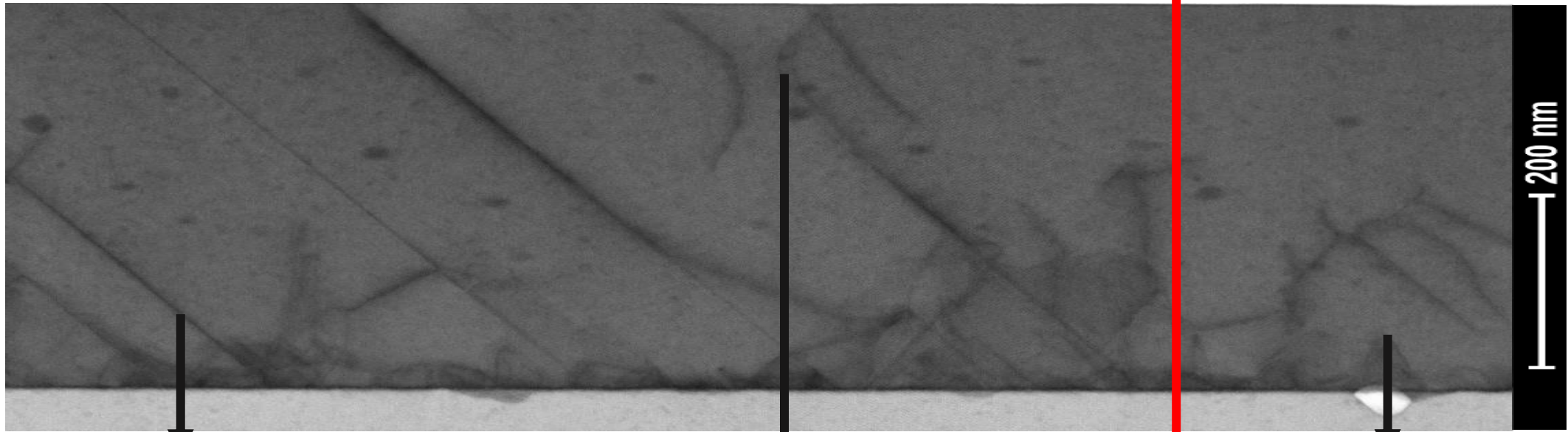


Material quality

Substrate preparation

Lattice mismatch

Polarity mismatch



Twins
Solved

Dislocations
Non radiative recombination
centers

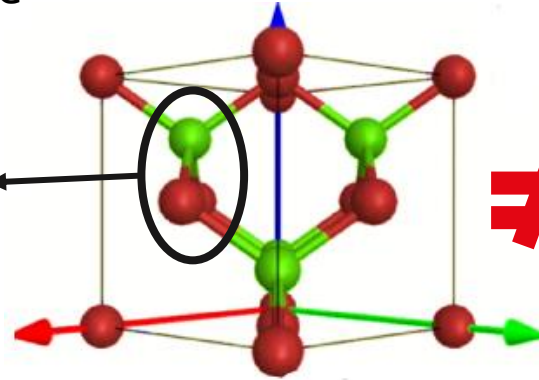
APBs
Short cuts

APBs kill devices

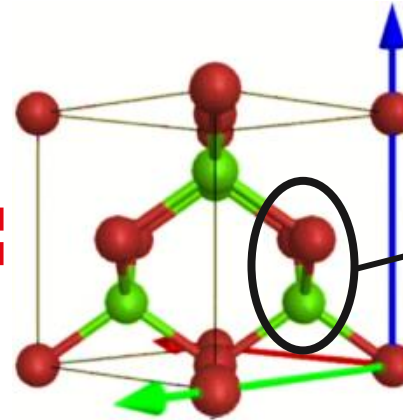
Antiphase boundaries (APBs)

Zinc Blend is polar (two types of atoms)

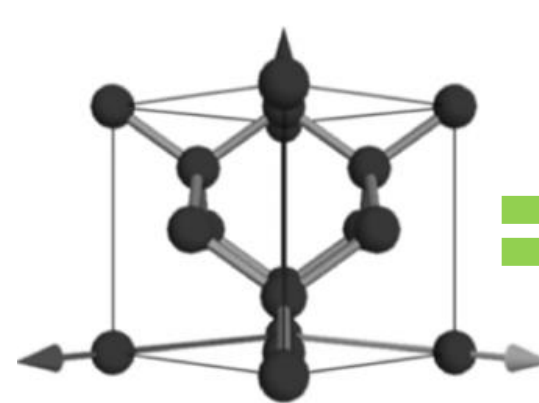
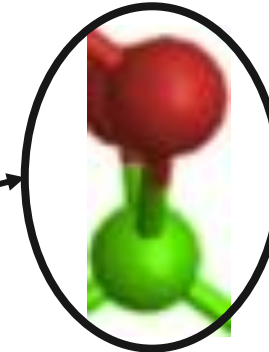
III-polar phase



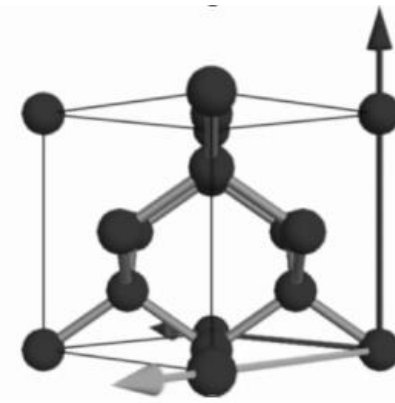
≠



V-polar phase



=

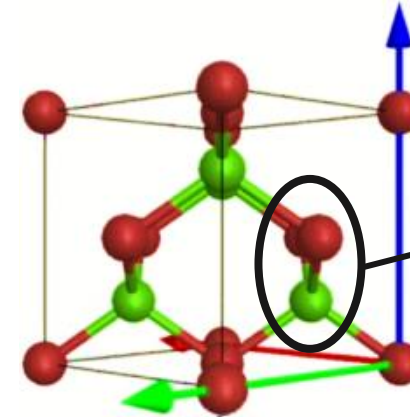
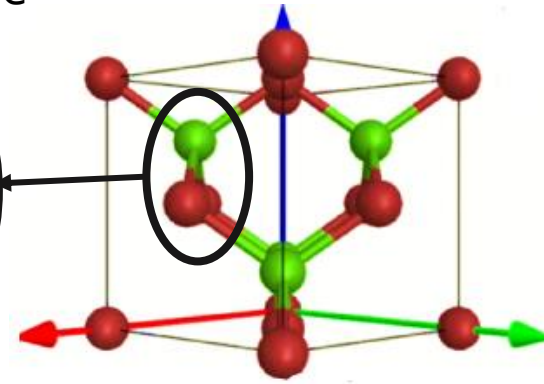


Si

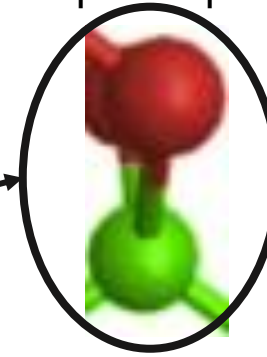
Diamond is non-polar (one atom)

Antiphase boundaries (APBs)

||| -polar phase

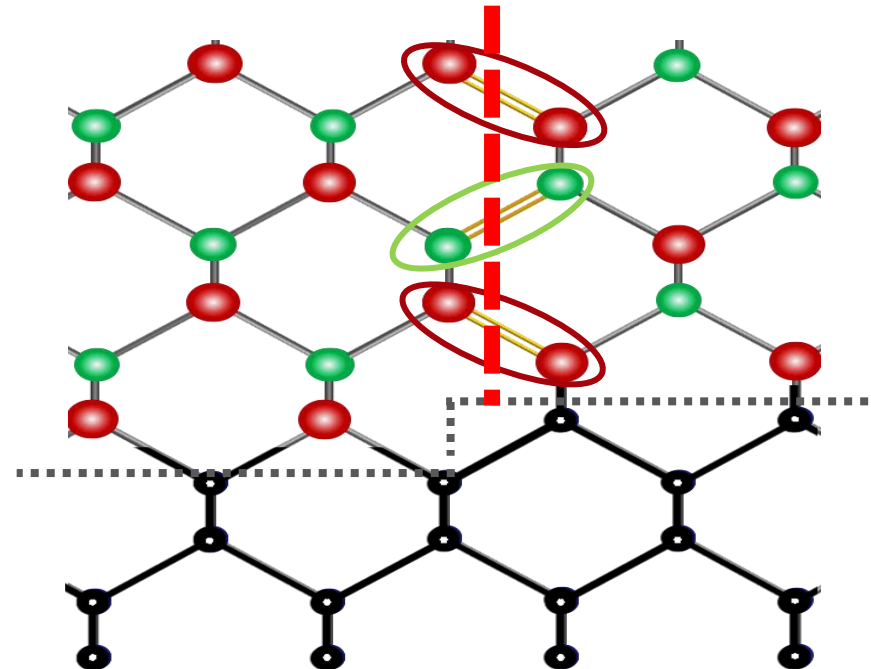


V-polar phase



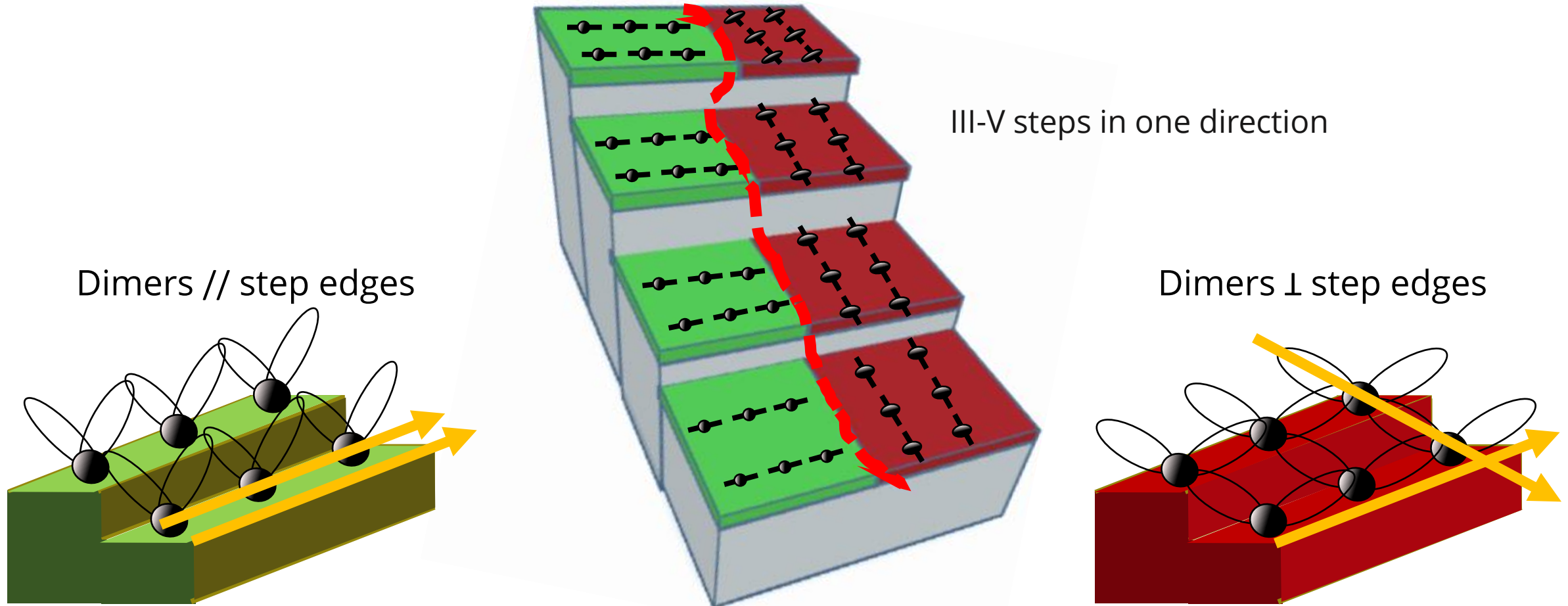
The two phases grow and nucleate

APB



Burying mechanism model

III-polar phase **APB** V-polar phase

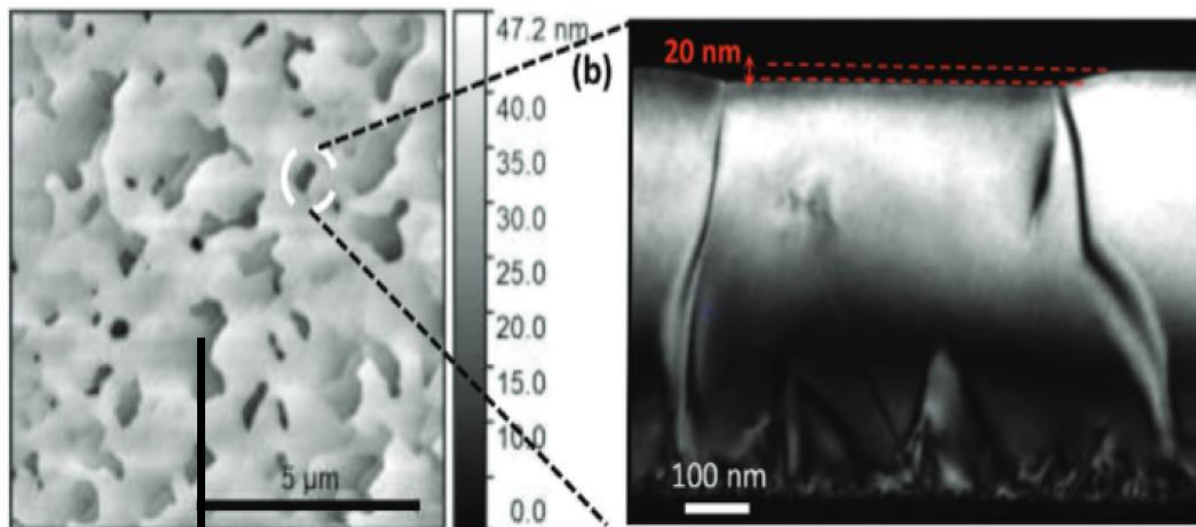


Different incorporation rates = the domain that grows slower is buried

Zinc-blende group III-V/group IV epitaxy: Importance of the miscut, C. Cornet *et al.* Phys. Rev. Mat.4, **053401** (2020), DOI:10.1103/PhysRevMaterials.4.053401

Experimental demonstration of the model: GaSb on Si 0.5°

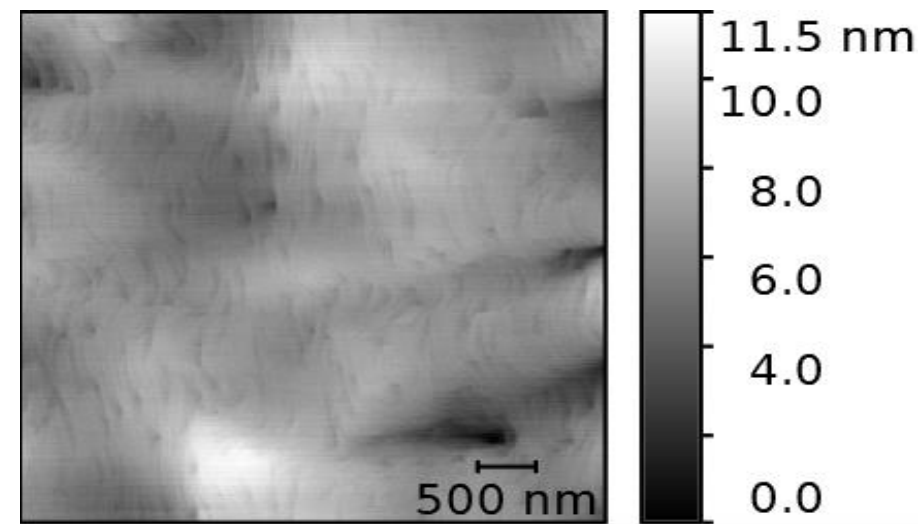
Before
500 nm GaSb on "on-axis" Si



Dark regions = APDs



After
500 nm GaSb on "on-axis" Si



No APDs



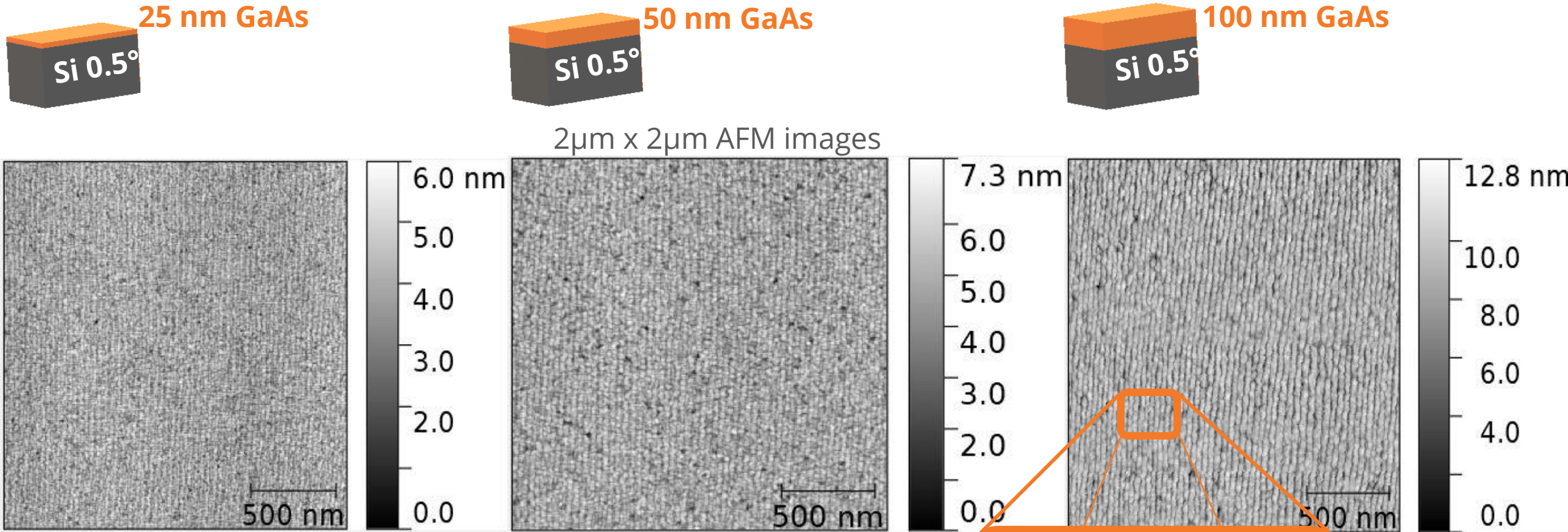
One domain is buried
Experiment consistent with model

With other III-V ?



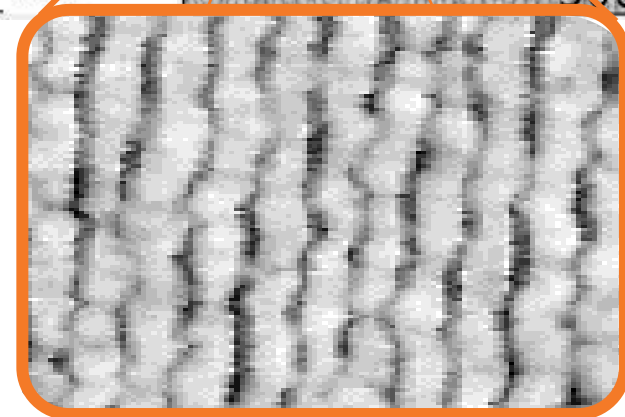
GaAs on 0.5° Si: growth and characterizations

Surface morphology of GaAs low temperature growths



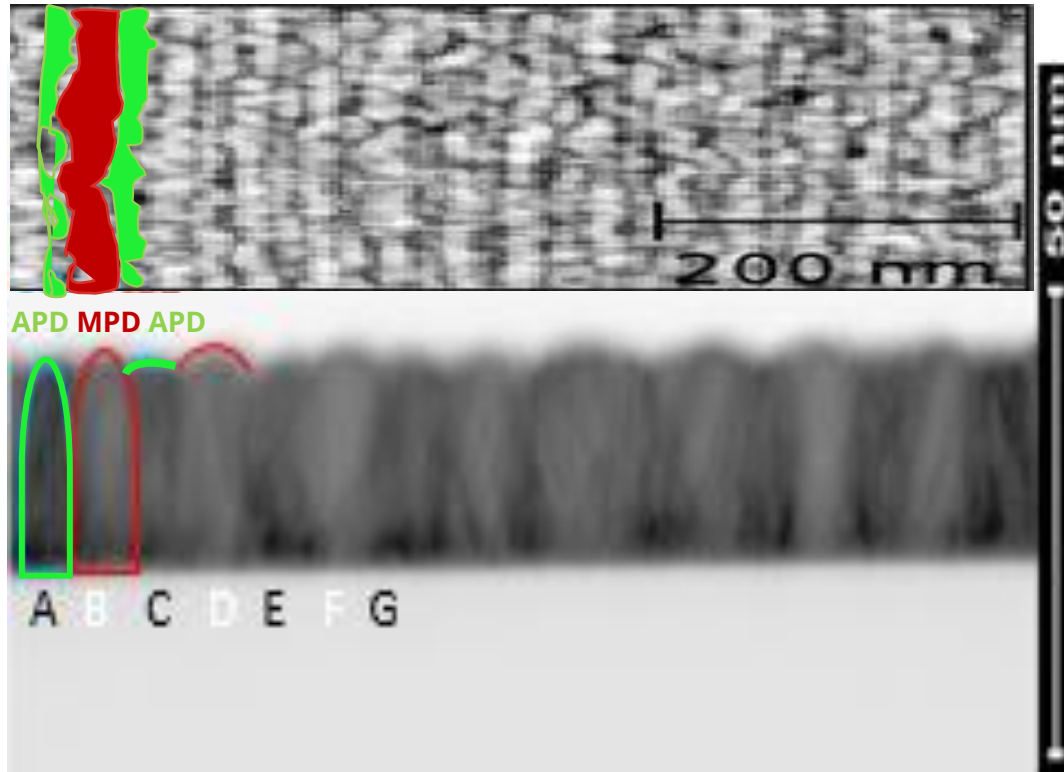
Surface covered with parallel elongated structures

Hypothesis: regular succession of APD-MPD
dark trenches = APBs

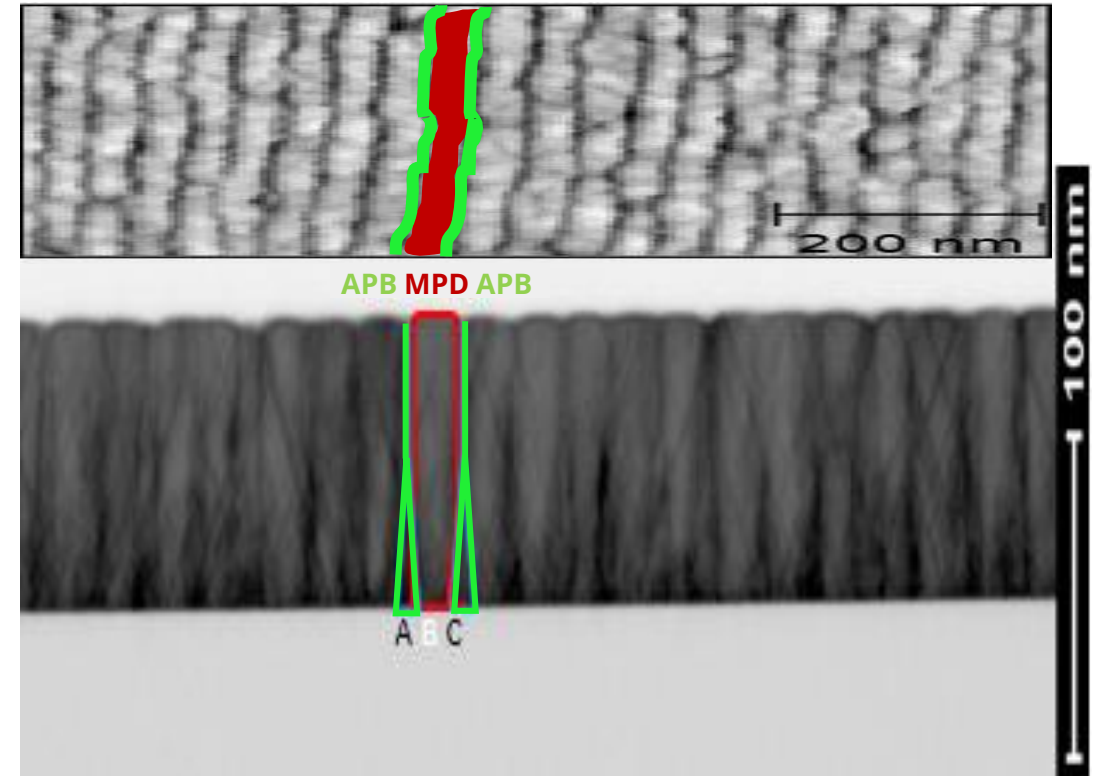


TEM confirms APD-MPD sequence and MPD overgrowth

25 nm GaAs



100 nm GaAs



Regular repetition **APD-MPD** (dark-clear regions)
MPD grows faster

Periodic repetition

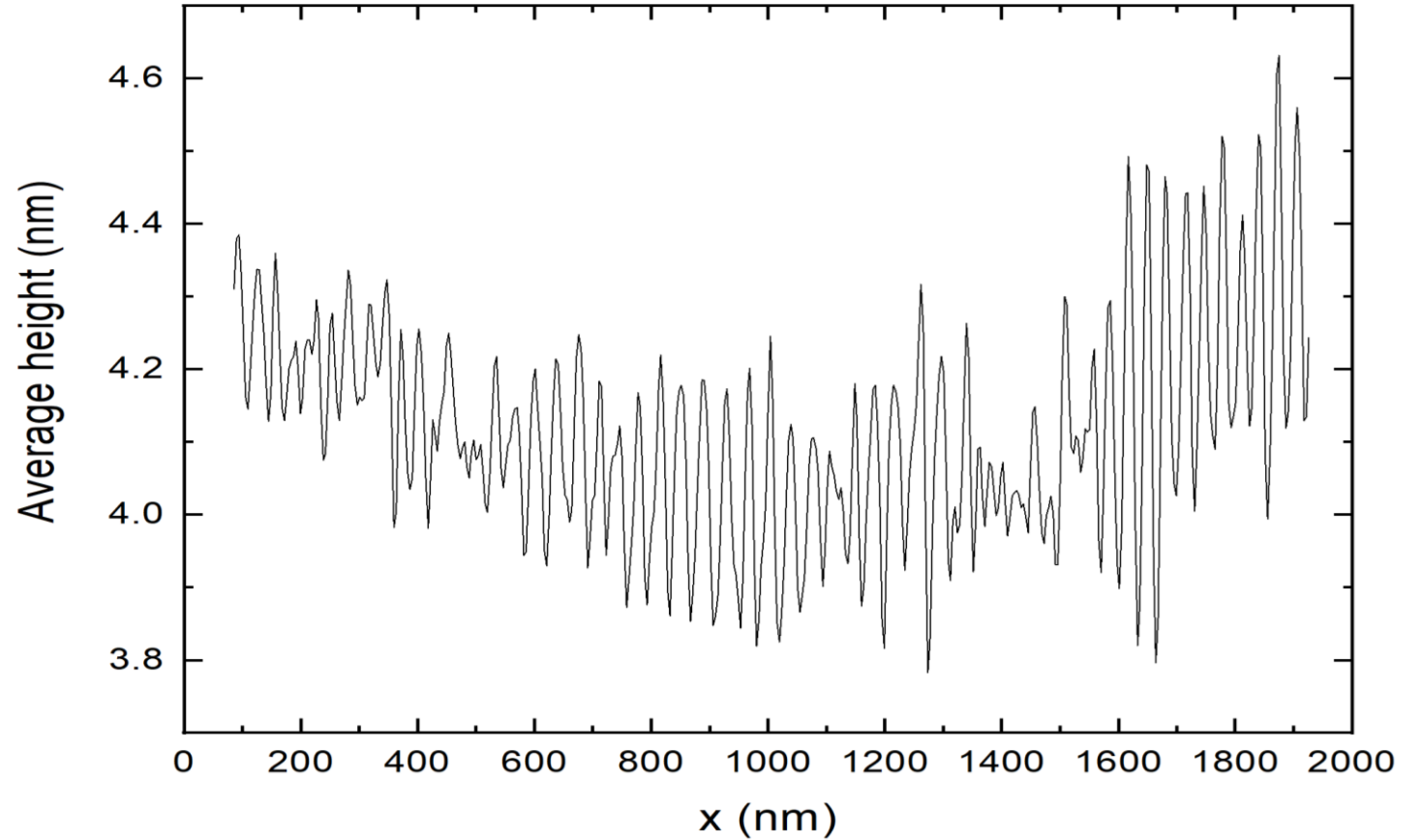
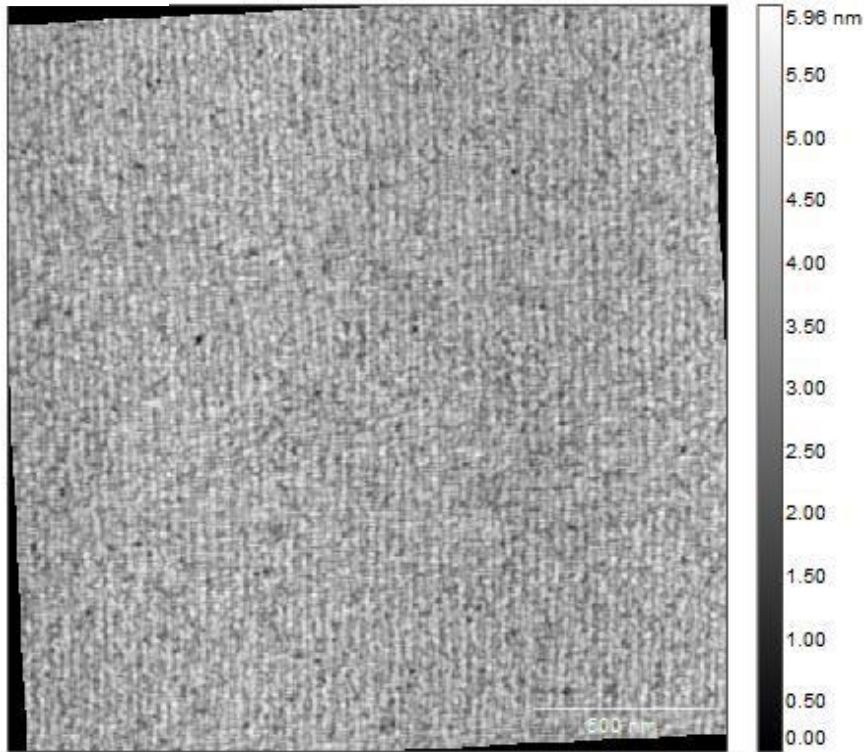


GaAs periodic distribution of APD-MPD

Repetition size is determined by AFM

25 nm GaAs

Si 0.5°

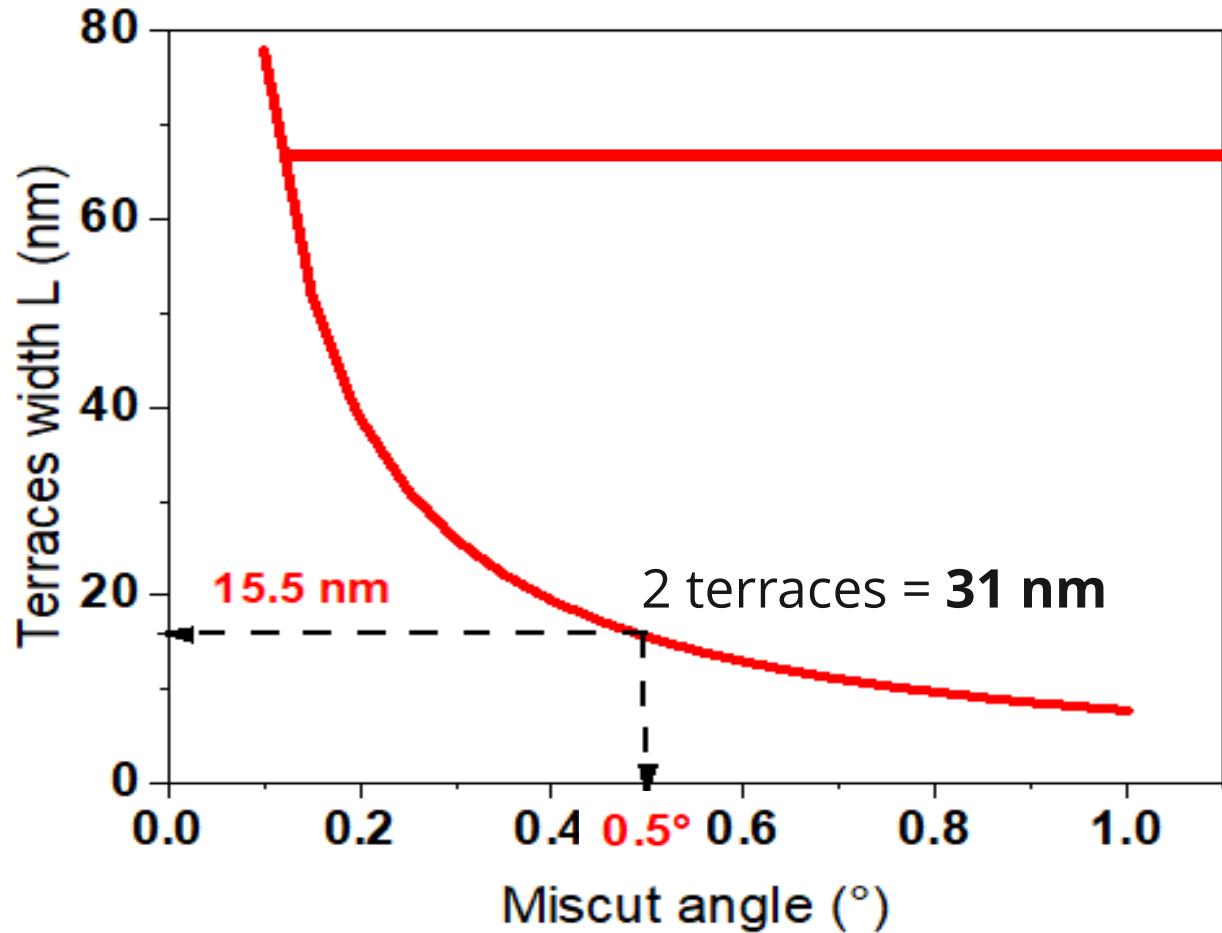


Average periodicity on $2\mu\text{m} \times 2\mu\text{m}$ AFM of 25 nm GaAs

=

31.7 nm

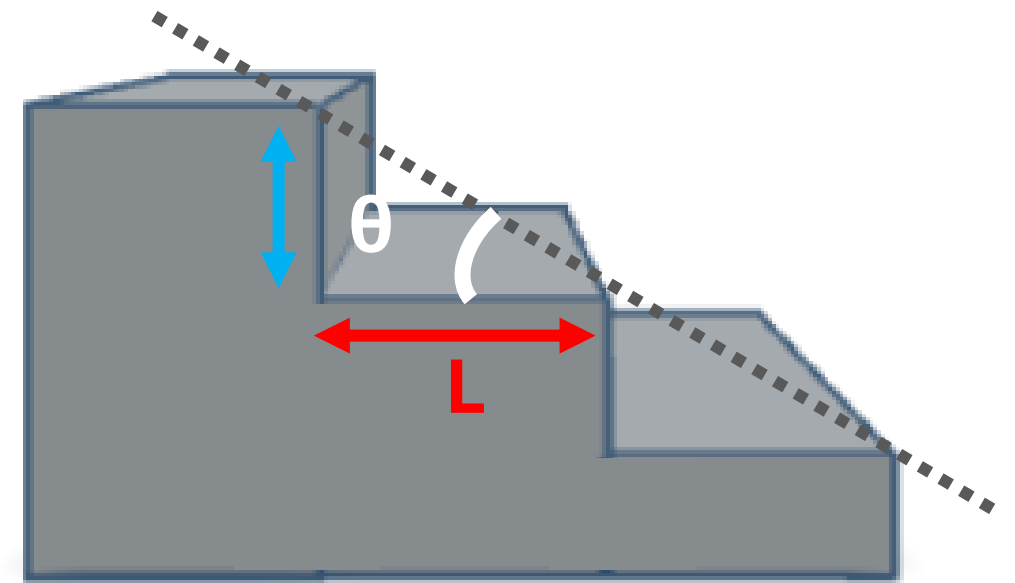
Si 0.5° mono-atomic terraces width determination



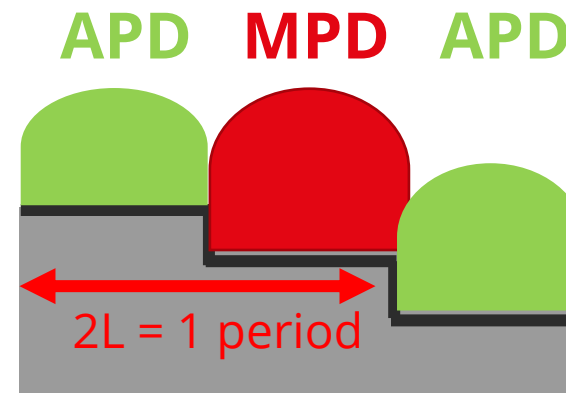
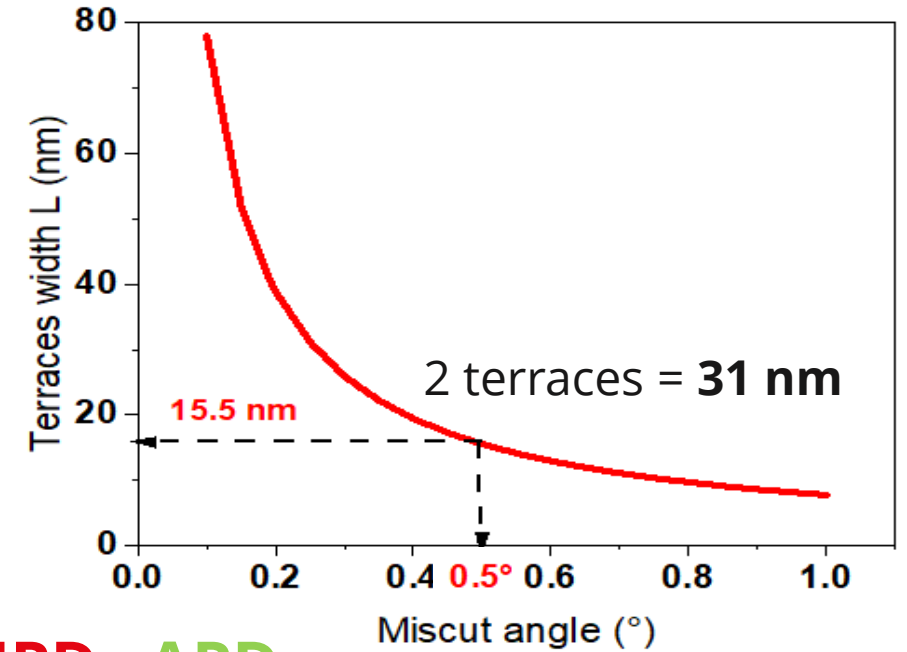
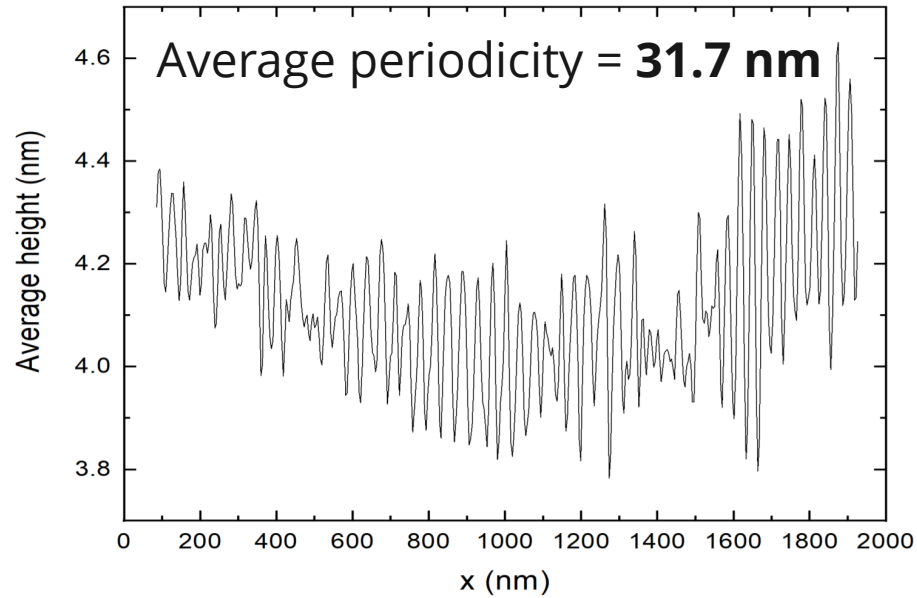
$a_{Si} = 0.54$ nm (300 K)

Mono-atomic steps height = $a_{Si} / 4$

Terrace width $L = a_{Si} / (4 \times \tan(\theta))$

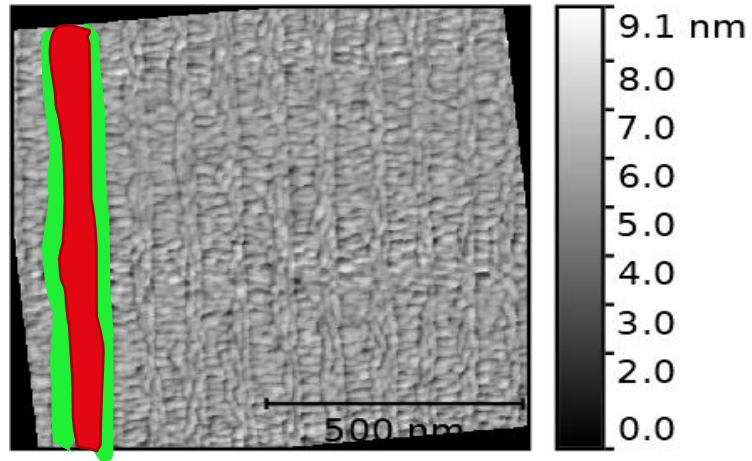


Si 0.5° mono-atomic terraces width determination

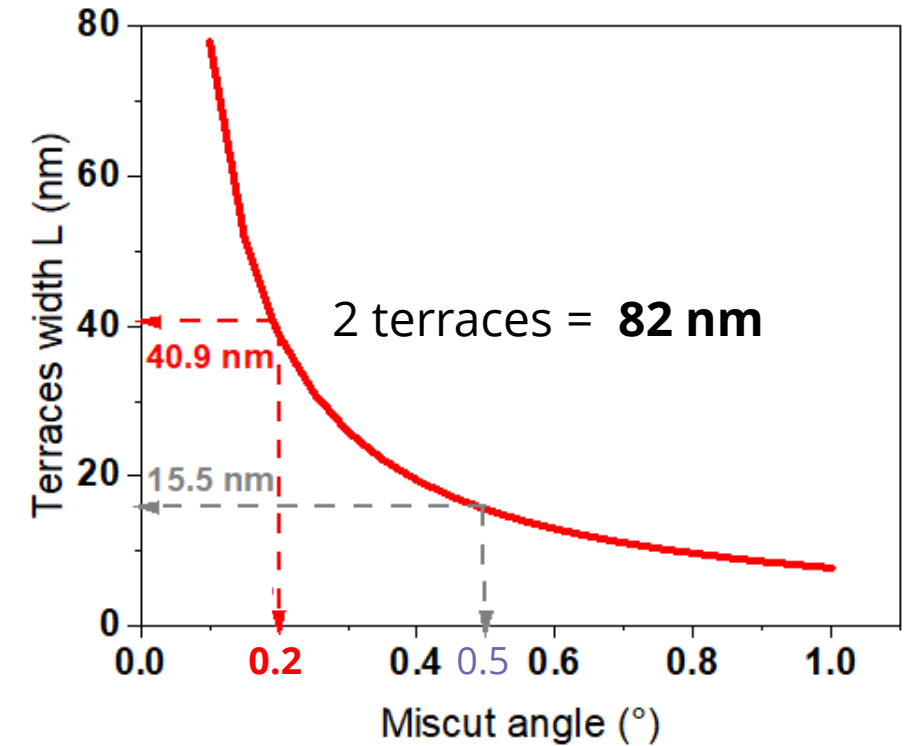


1 domain width = 1 Si terrace width

Determination of period width with 0.2° miscut

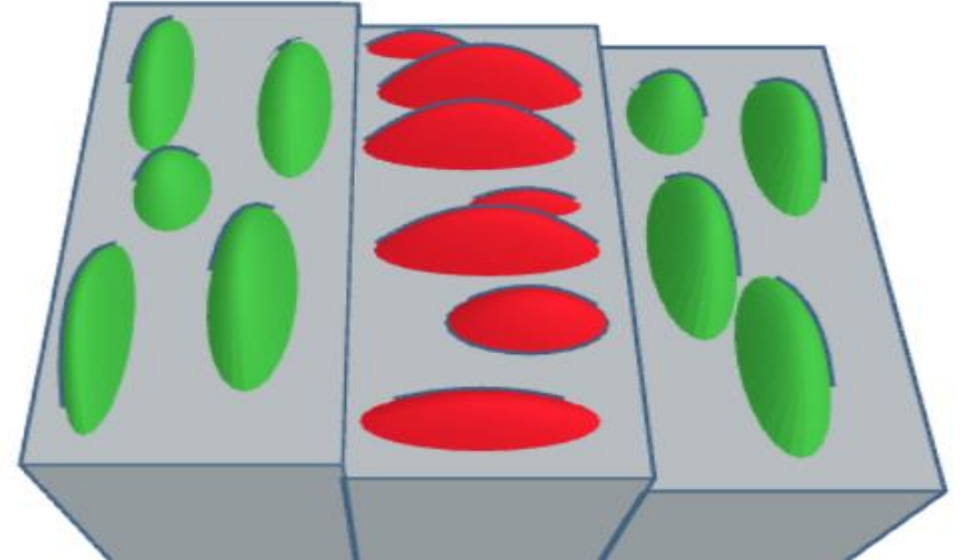
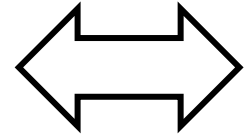
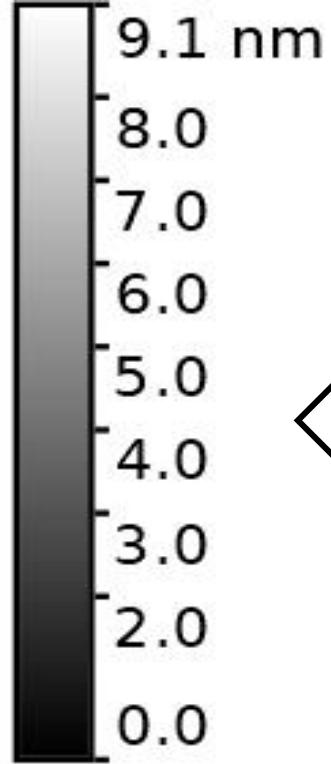
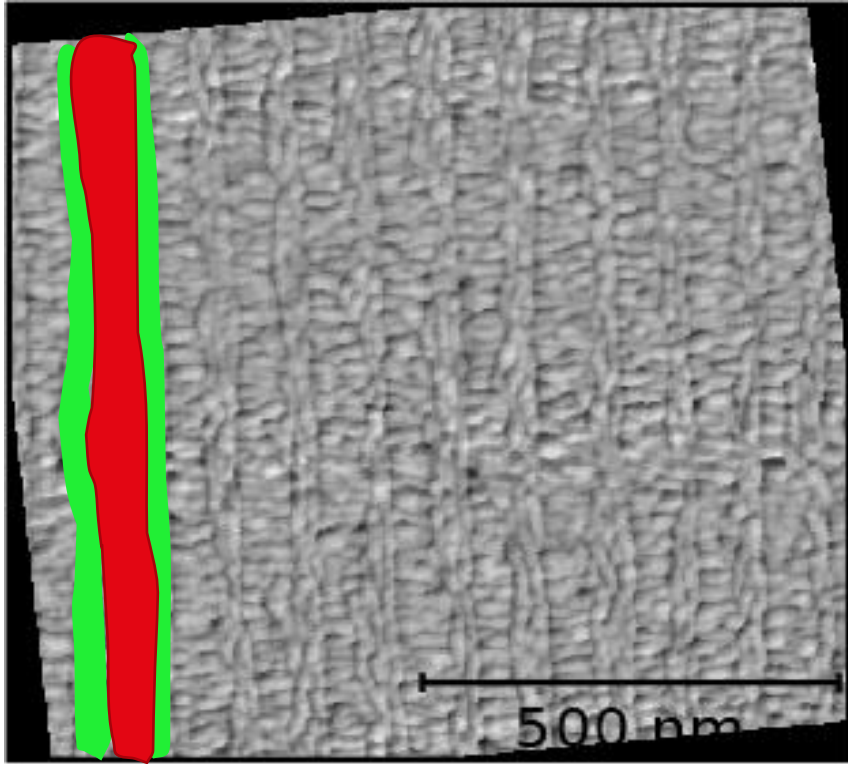


Average periodicity on 2 μm x 2 μm AFM = **82 nm**



1 domain on 1 Si terrace

Islands organization for 50 nm GaAs on 0.2° Si

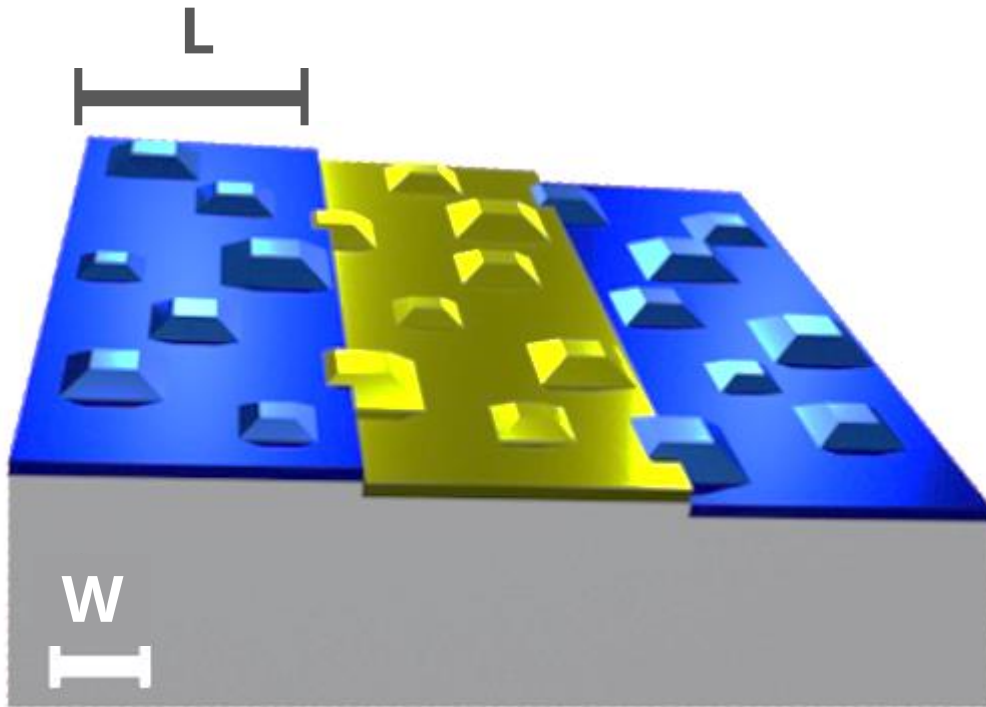


Perpendicular domains
1 phase on 1 Si mono-atomic terrace
=

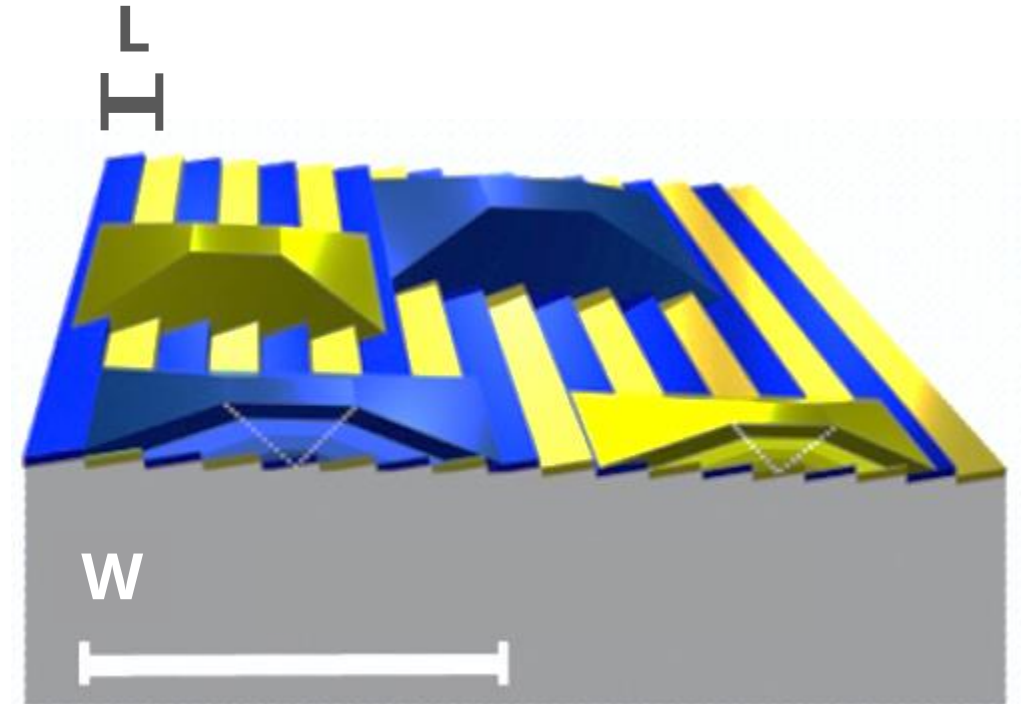
Initial 3D islands are smaller than Si terraces

Regime transition

Terrace-driven $W < L$



Nucleation-driven $W > L$

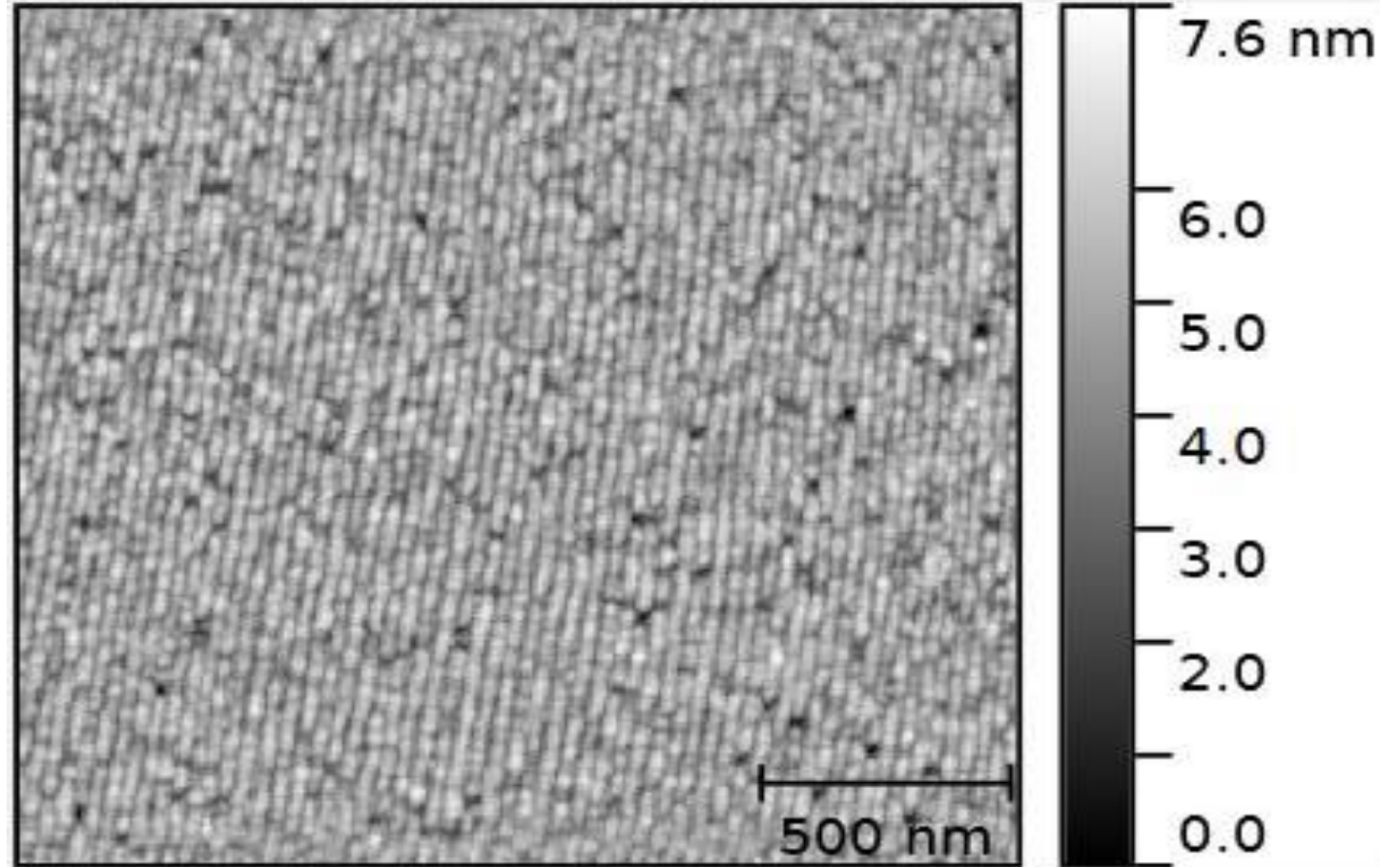
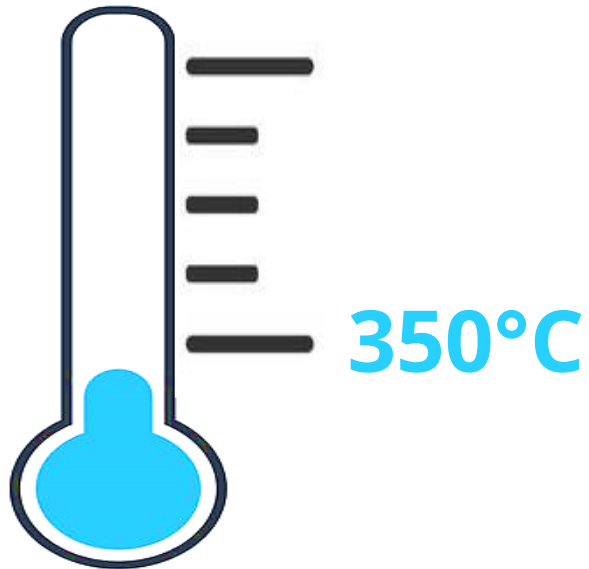
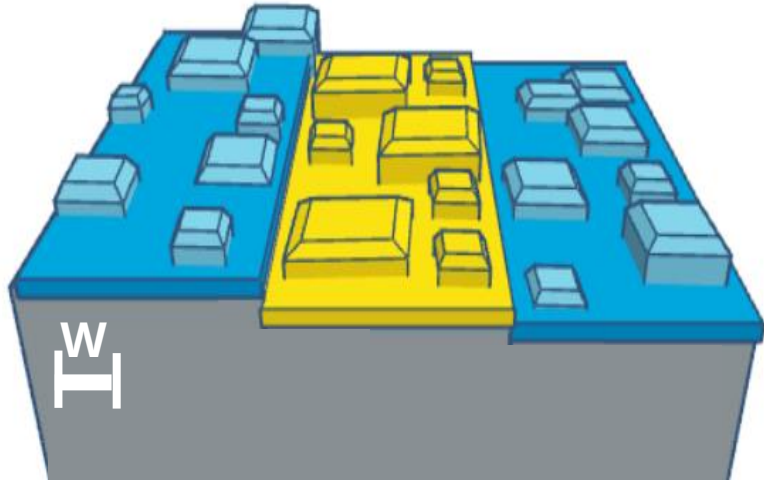


Temperature rise = regime transition

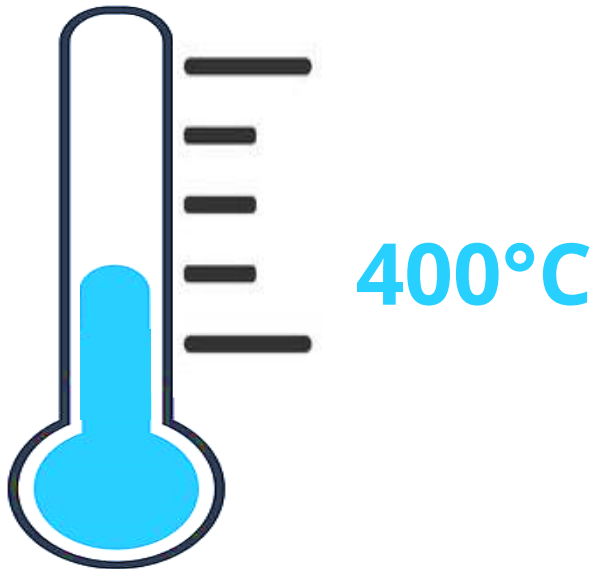
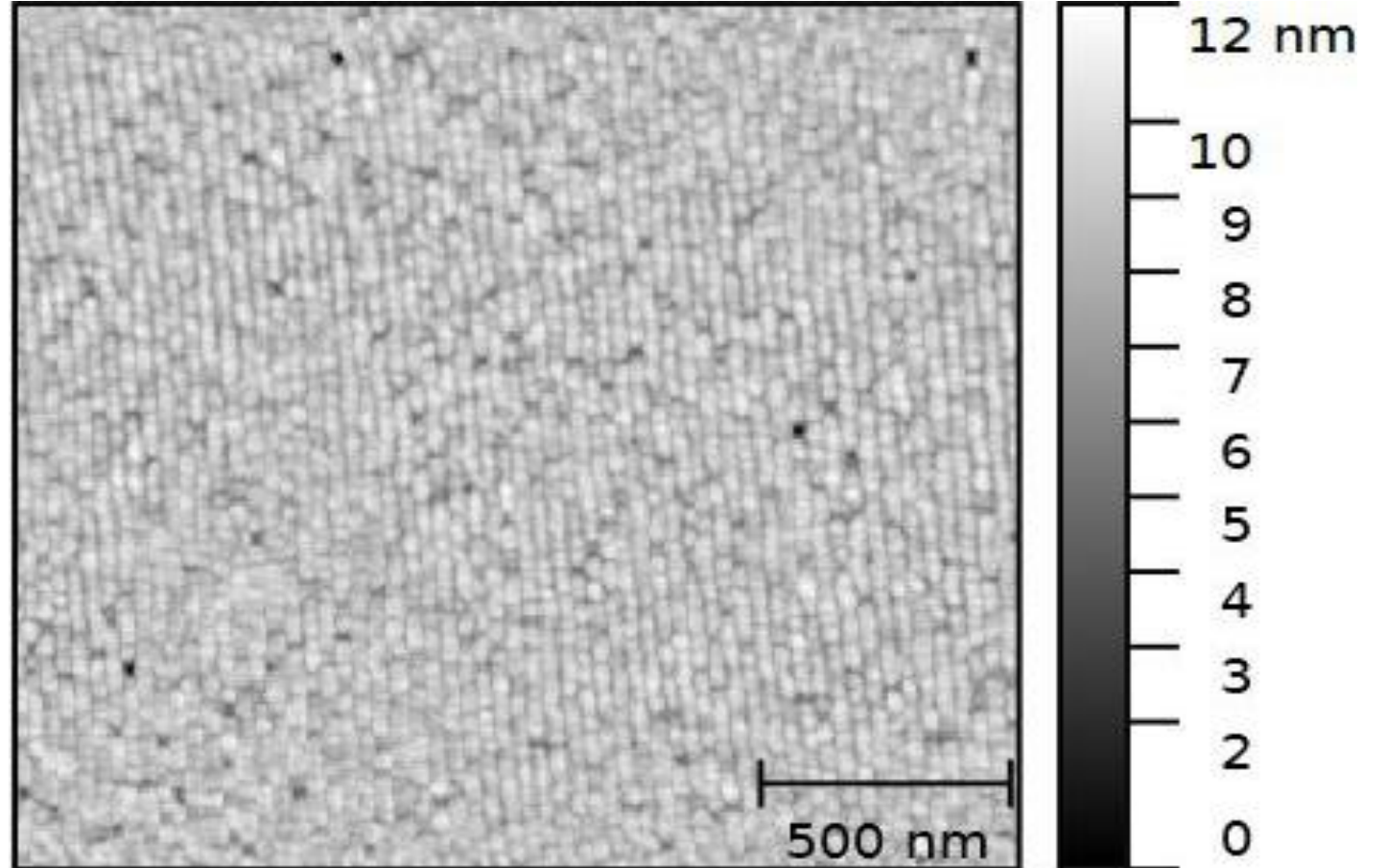
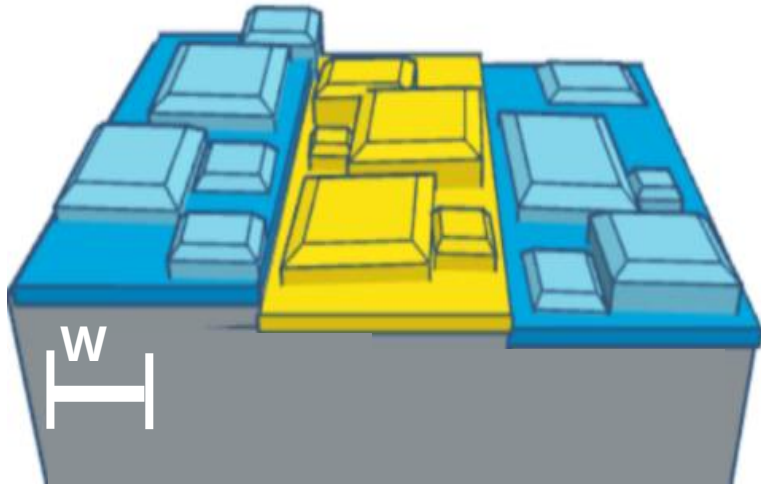


Growth conditions influence on stable island size

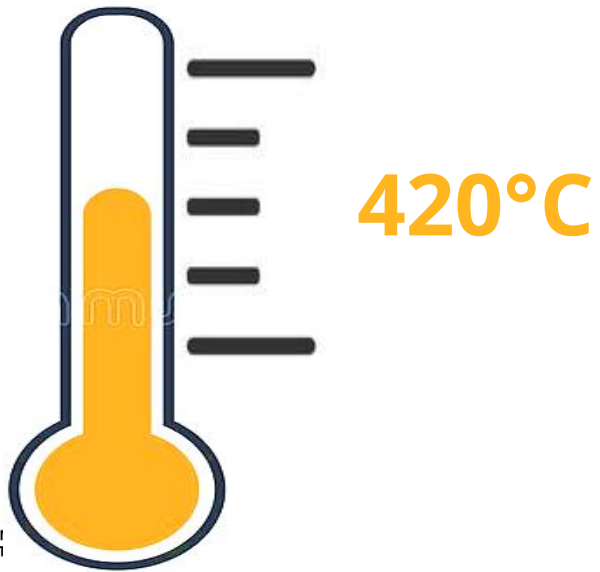
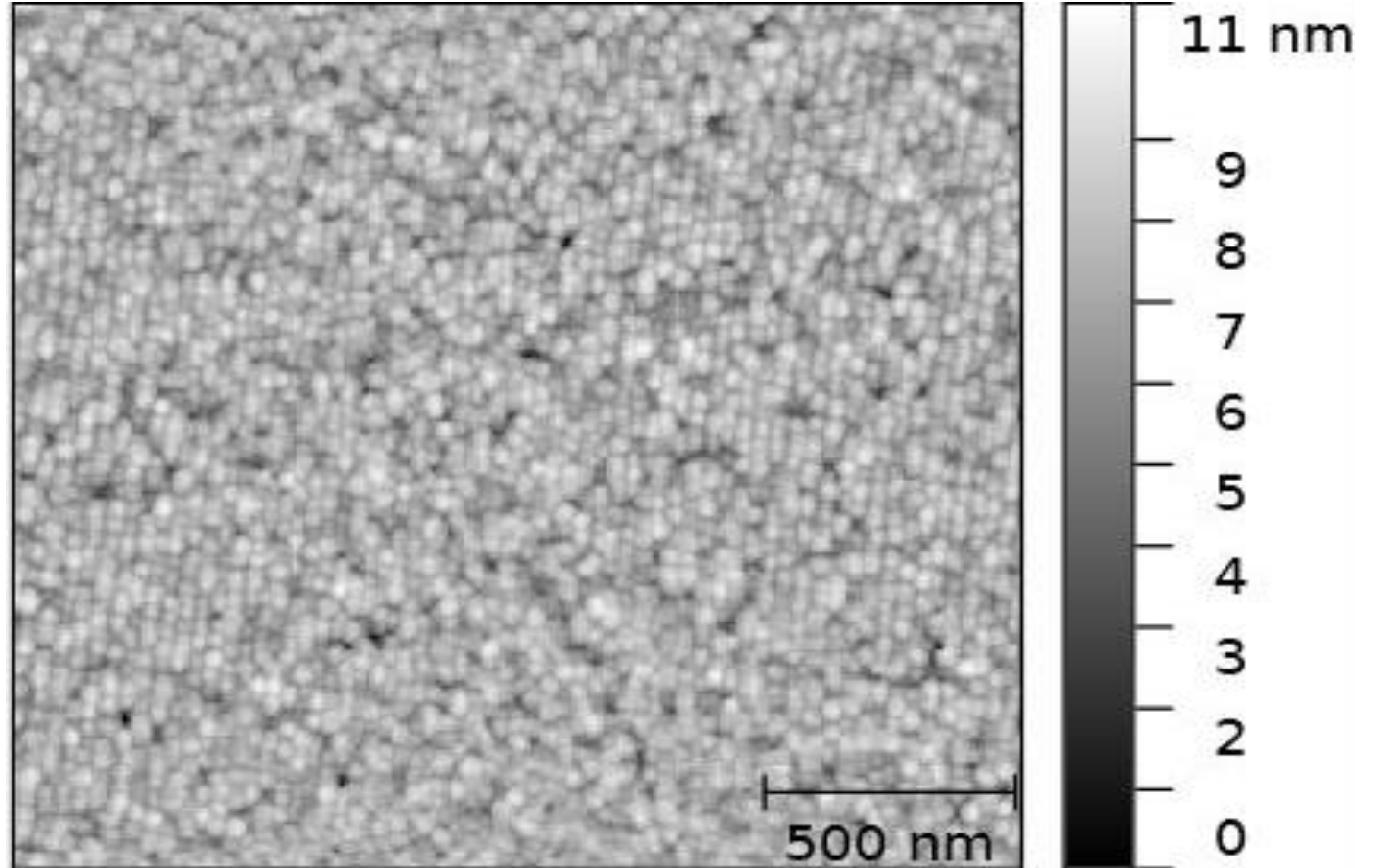
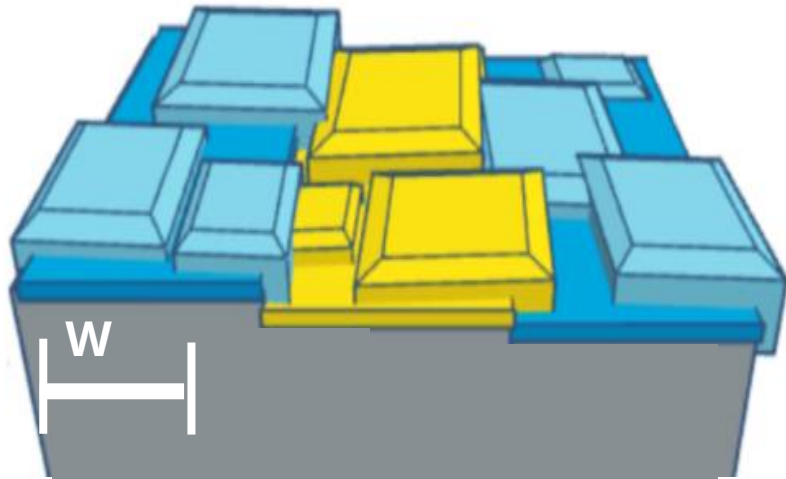
Temperature dependent evolution of the stable island size



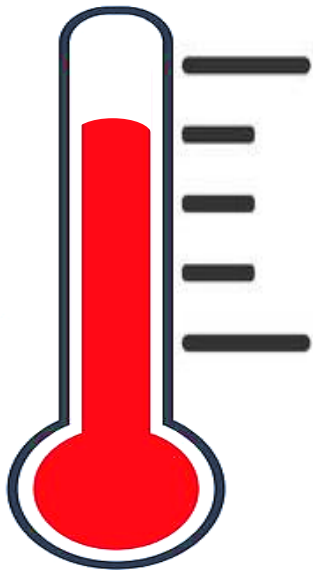
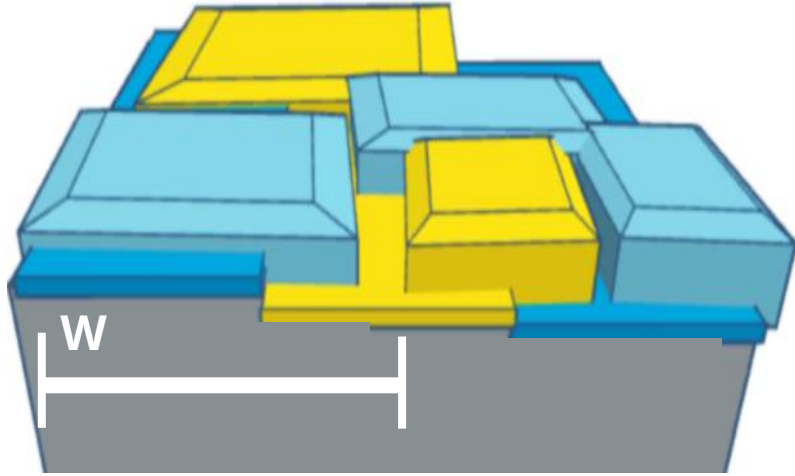
Temperature dependent evolution of the stable island size



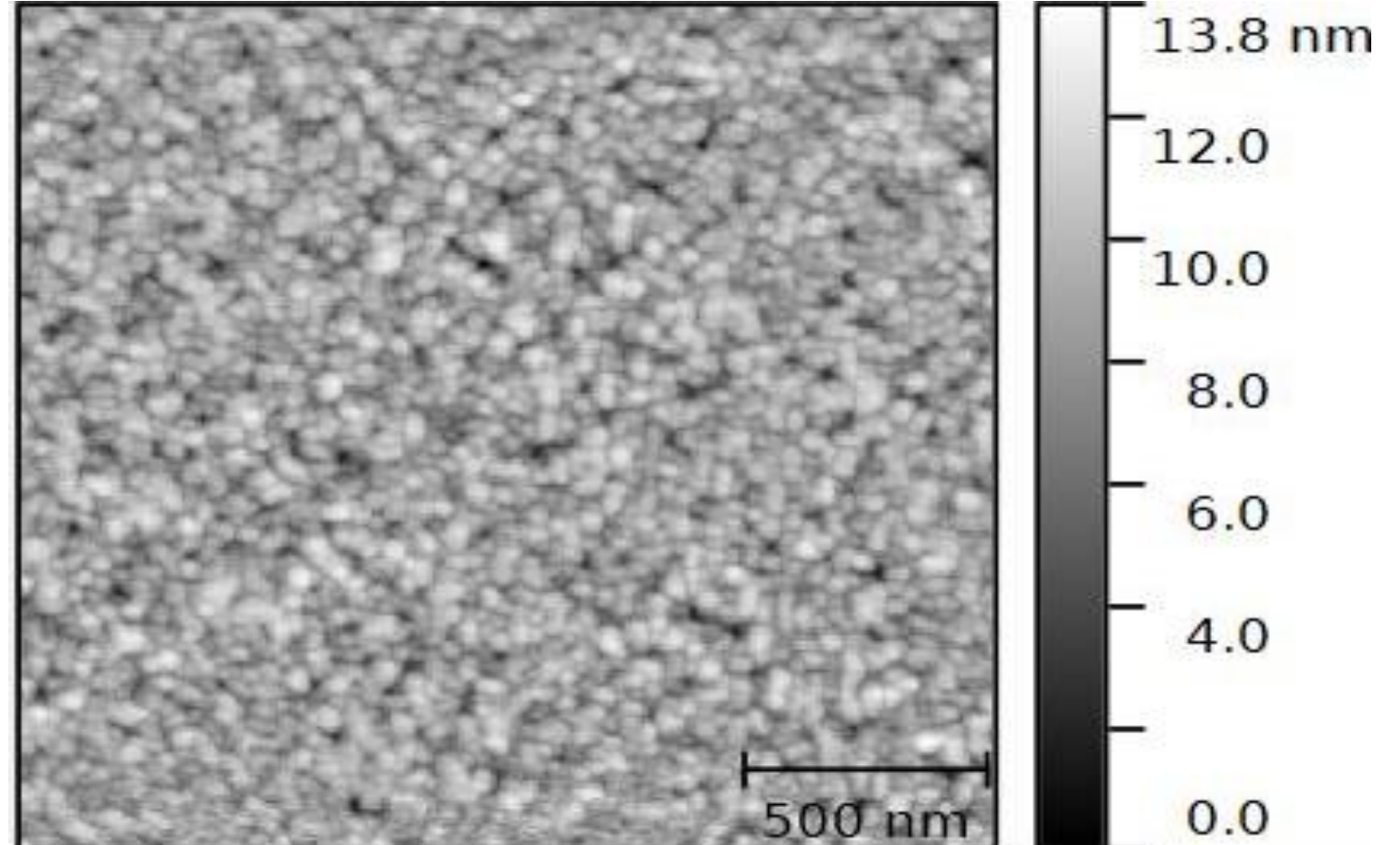
Temperature dependent evolution of the stable island size



Temperature dependent evolution of the stable island size

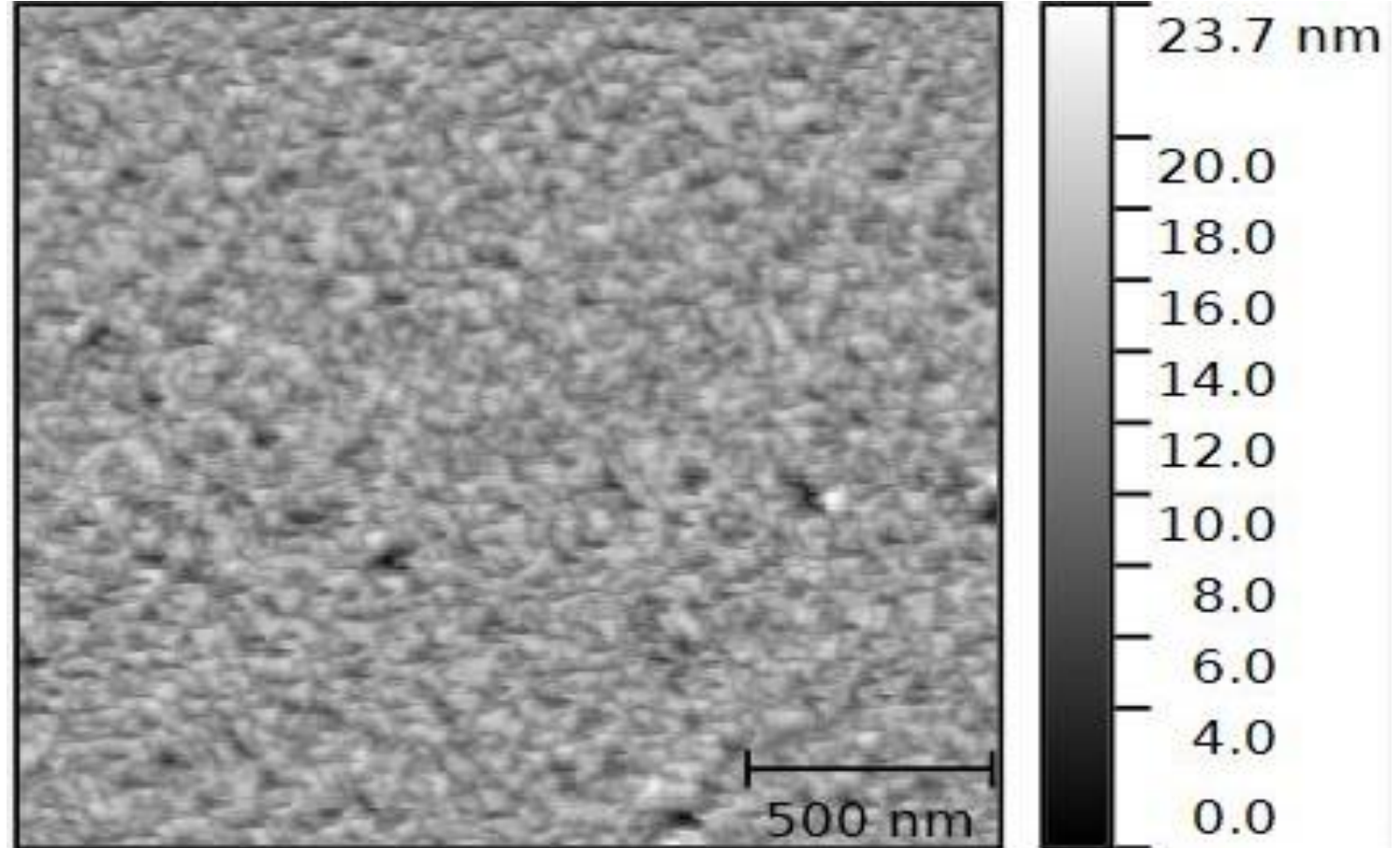
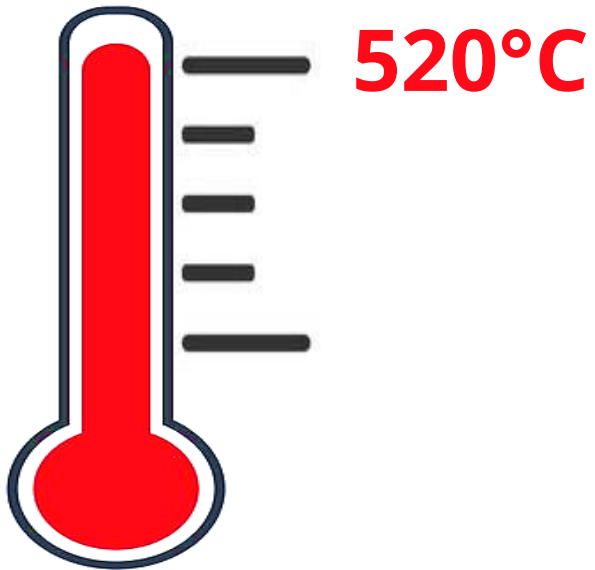
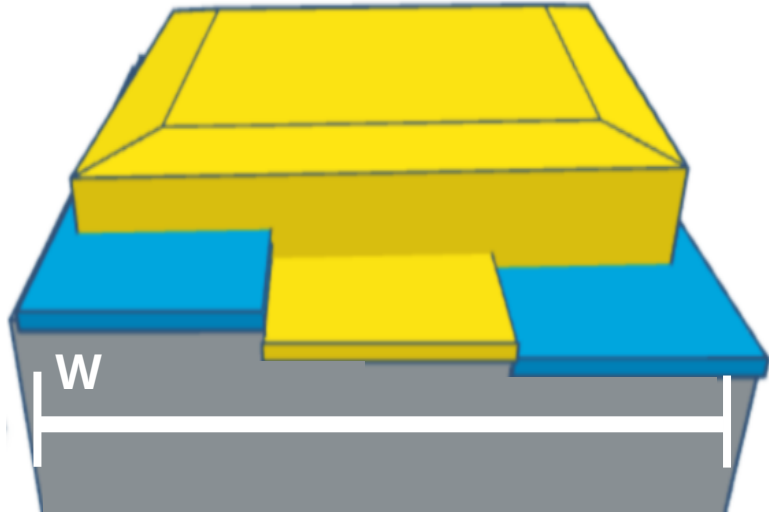


470°C



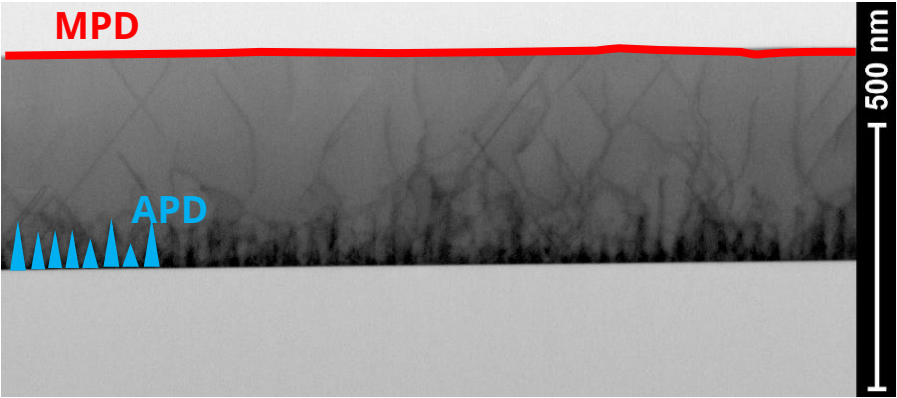
Disorganization of surface
Size of island > Si terrace width

Temperature dependent evolution of the stable island size



Disorganization of surface
Size of island > Si terrace width

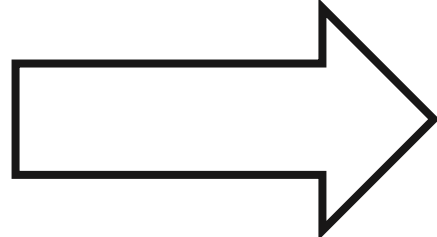
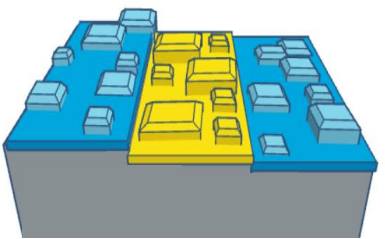
Burying mechanism demonstrated for GaAs on Si



500 nm GaAs APBs-free layers

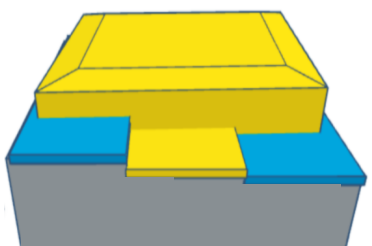
GaAs terrace driven regime

350°C



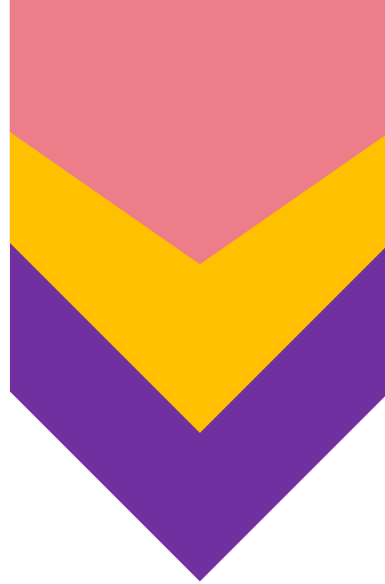
nucleation driven

520°C



Next: Validation of APDs burying model for other III-Vs and alloys on group IV substrates

Use these APB-free samples as templates to grow devices



Thank you for your attention