

Distribution initiale de phase et enfouissement des domaines d'antiphase lors de la croissance III-Vs/Si (001)

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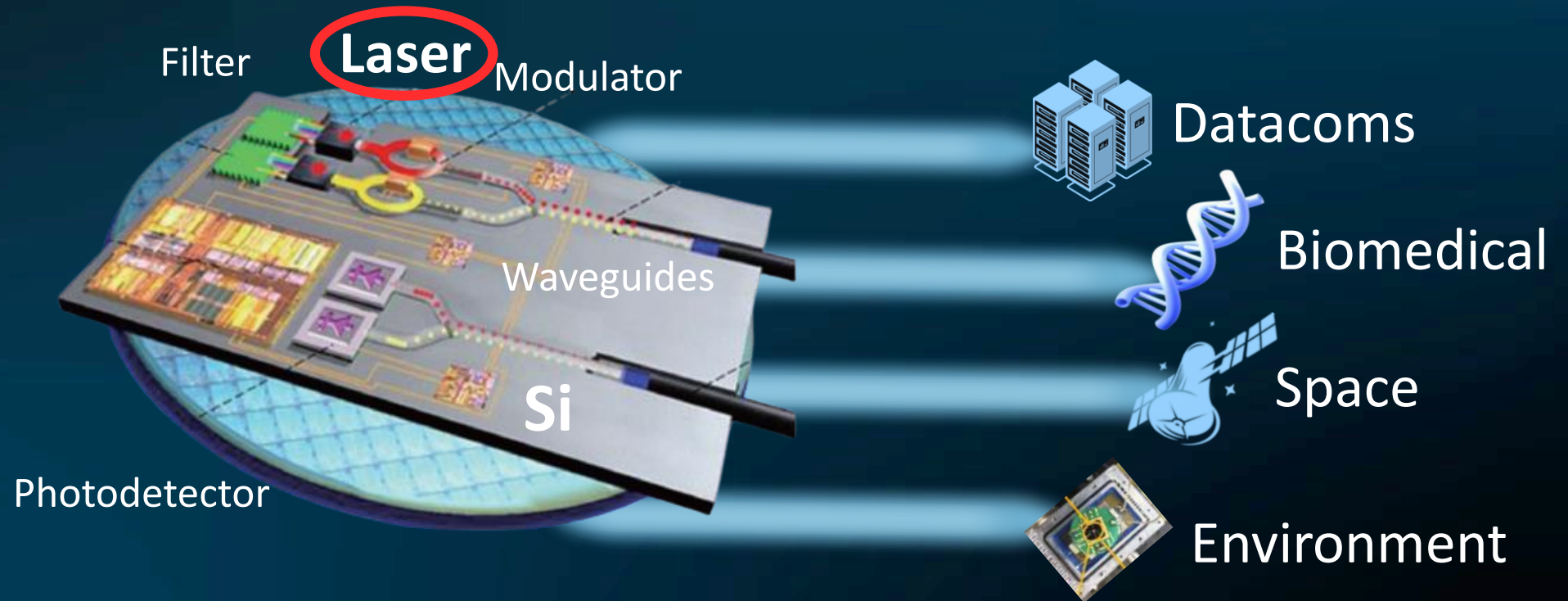
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² University of Rennes, Institut FOTON, INSA, CNRS, UMR 6082, 35000 Rennes, France

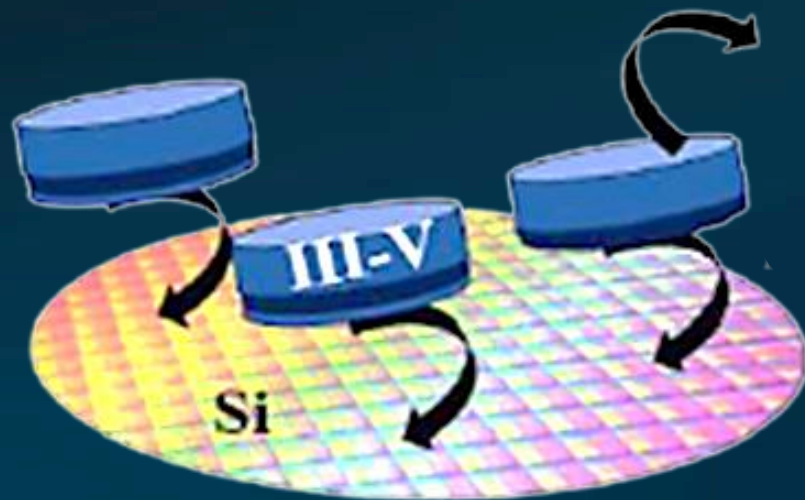
³ University of Paris-Saclay, C2N, CNRS, UMR 9001, 91120, Palaiseau, France

⁴ Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5-7, 10117, Berlin, Germany

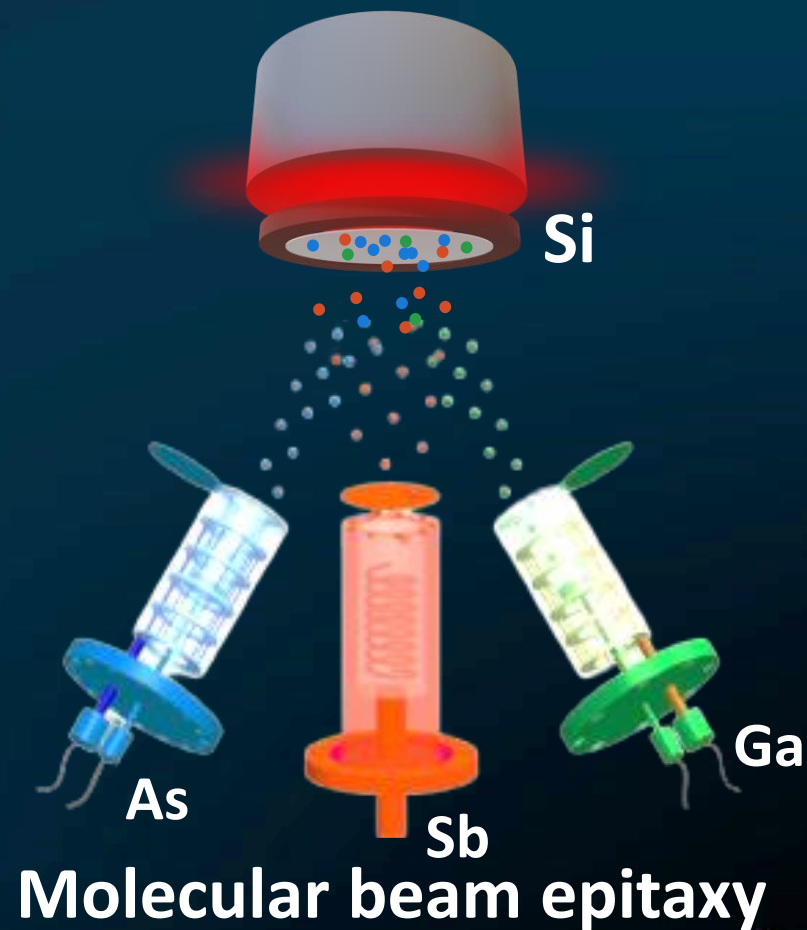
Photonic integrated circuits (PICs):



Heterogeneous integration



Monolithic integration



Molecular beam epitaxy

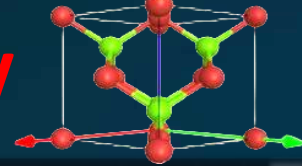
Challenges

Si



≠

III-V



Twins

Substrate preparation



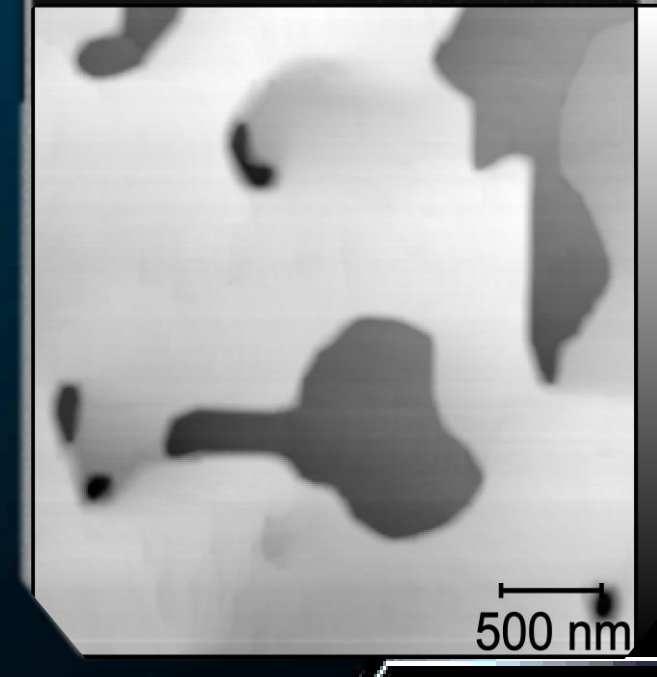
Dislocations

Lattice mismatch



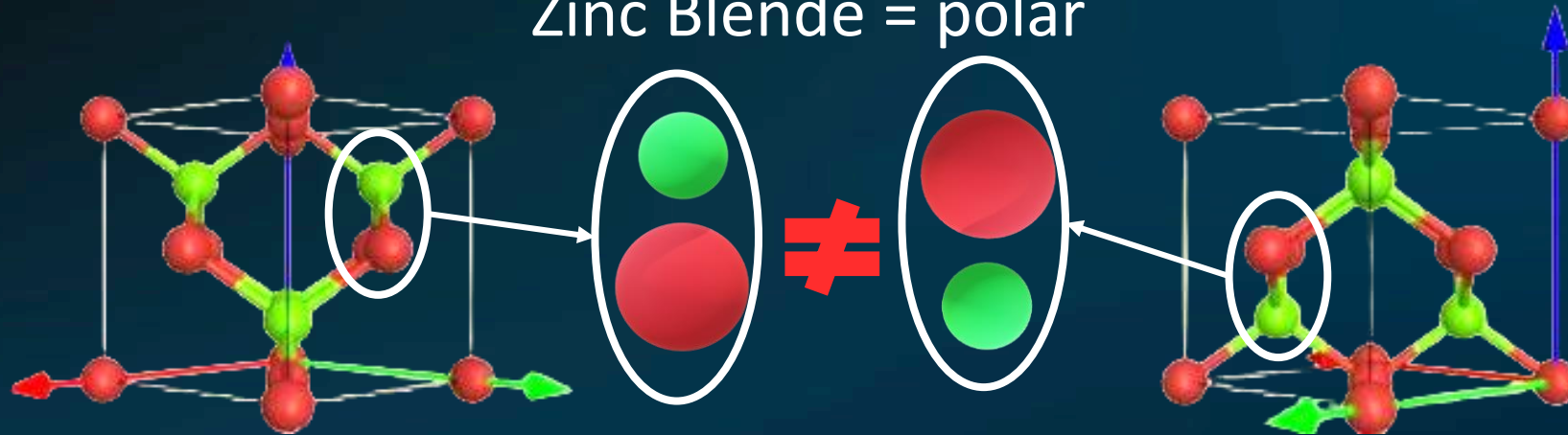
APBs

Crystal symmetries

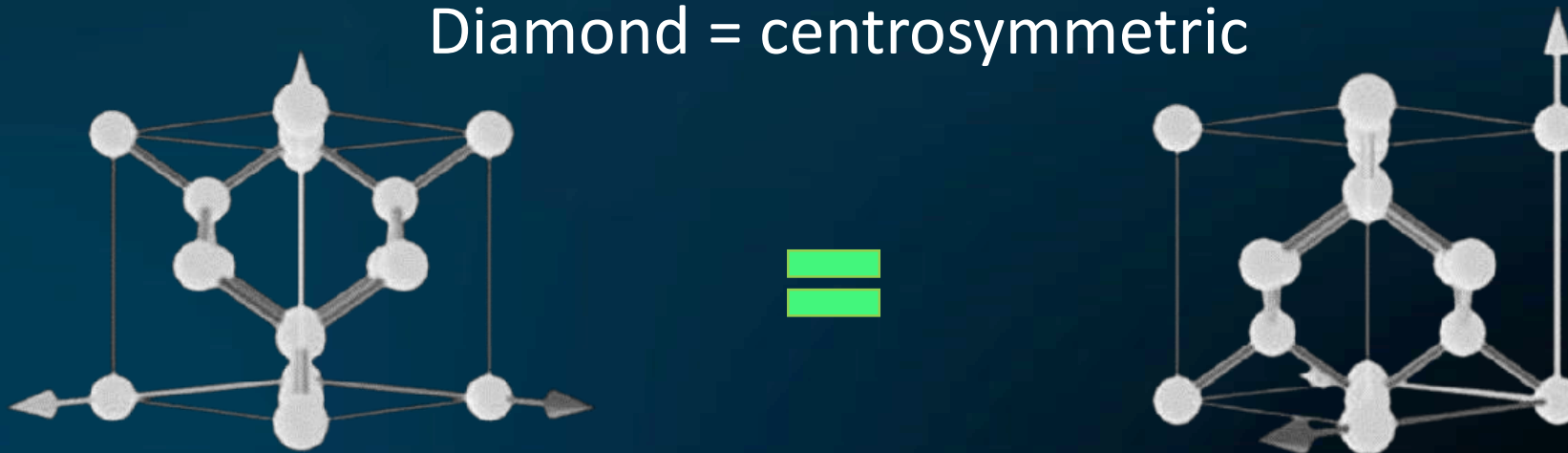


Challenges

Zinc Blende = polar



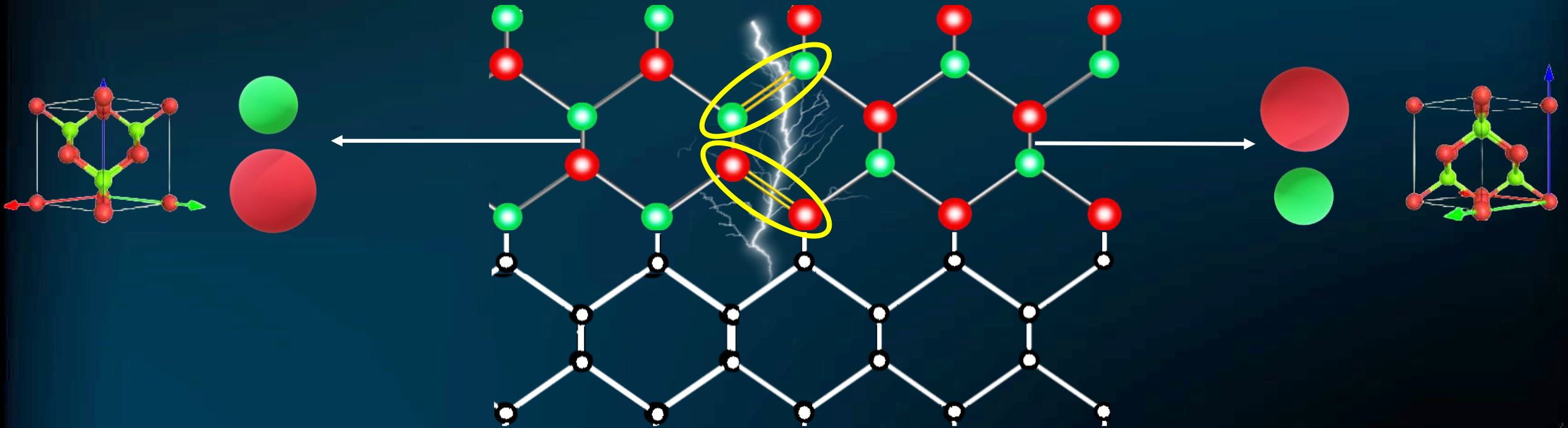
Diamond = centrosymmetric



Higher degree of symmetry

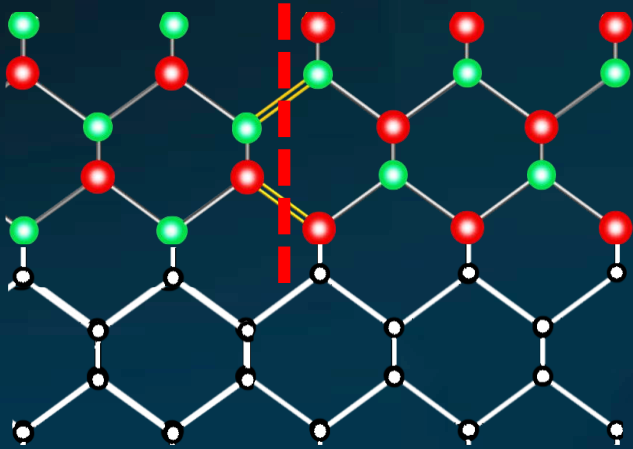
Challenges

Short-cut

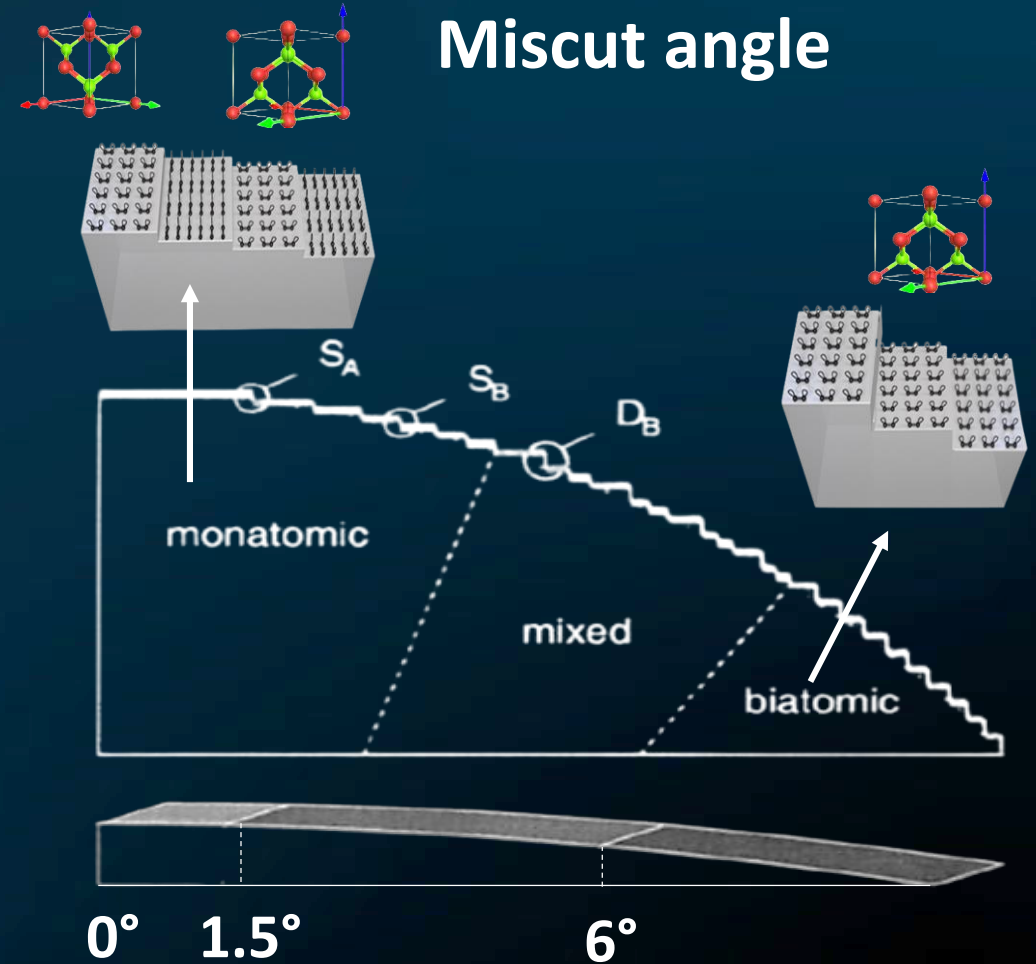


Challenges

APB



Miscut angle

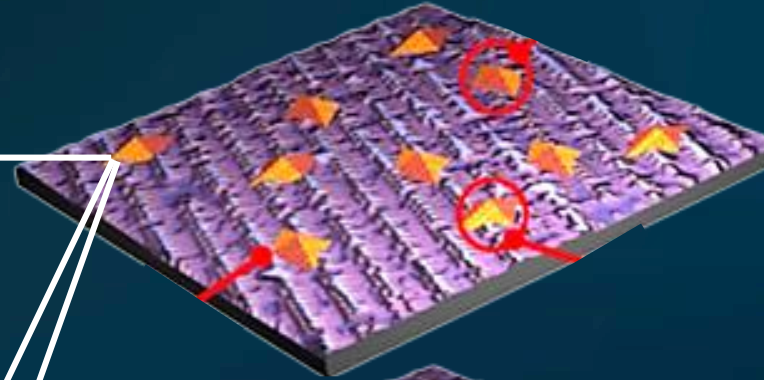
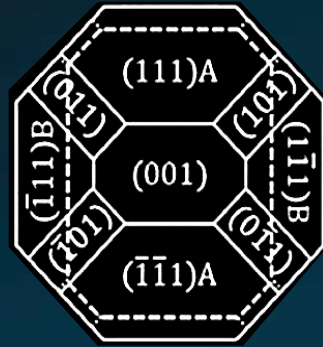


Few demonstrations of APB annihilation

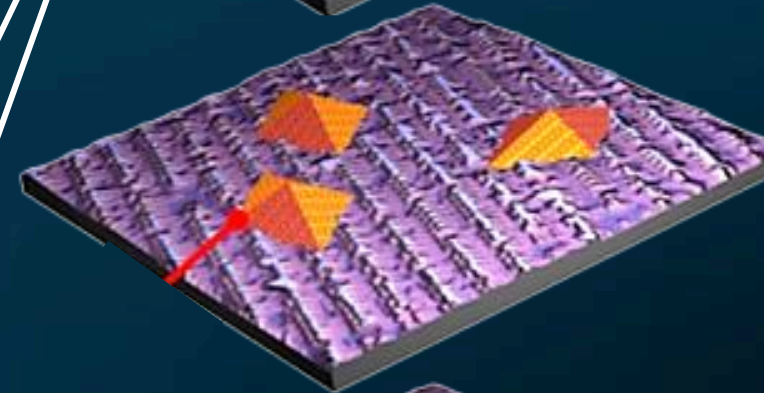
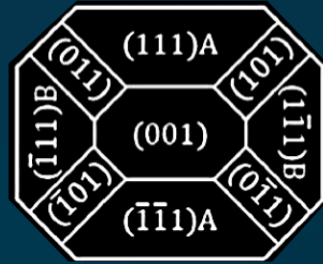


No clear explanation of the mechanism

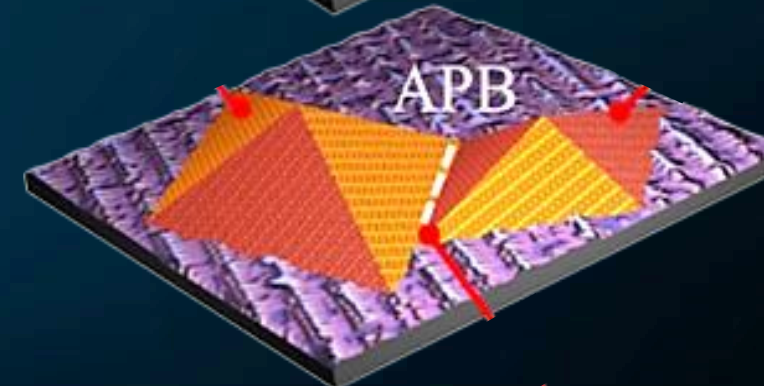
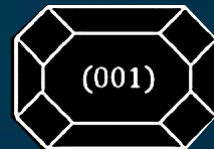
Volmer-Weber growth mode



III-V nuclei



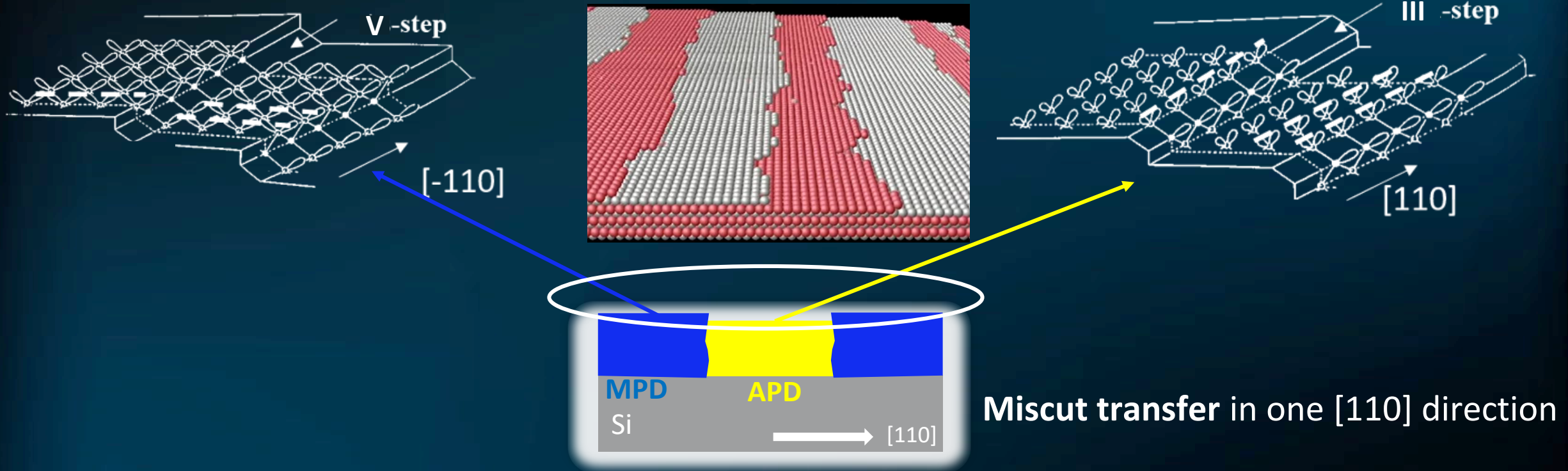
III-V 3D stable islands



Heterophase coalescence

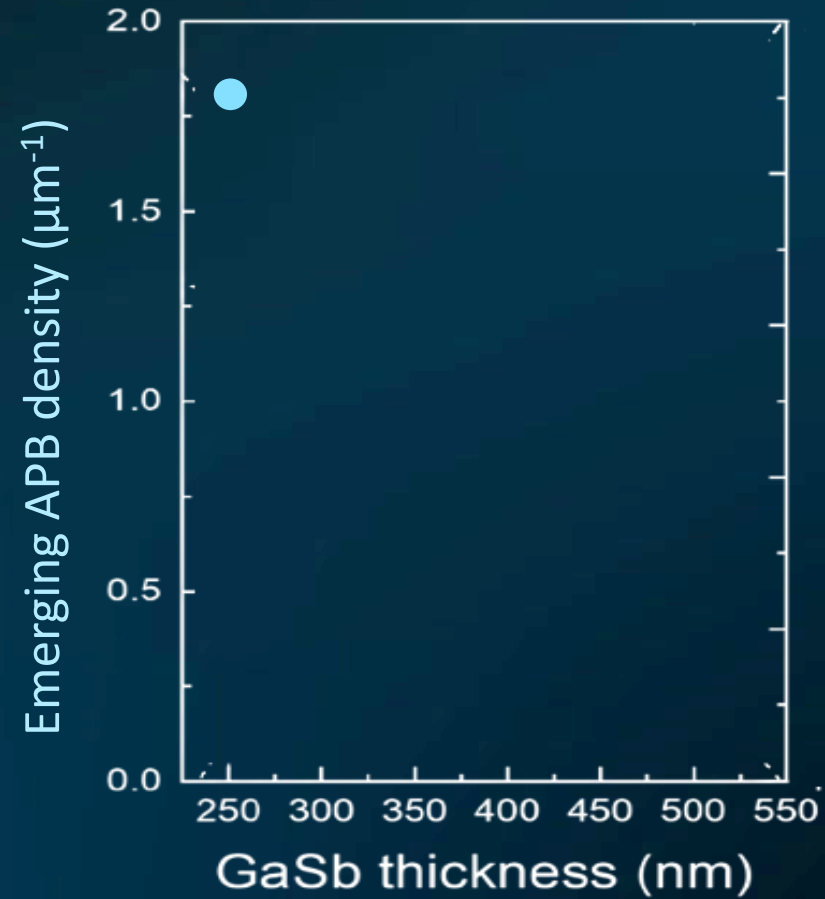
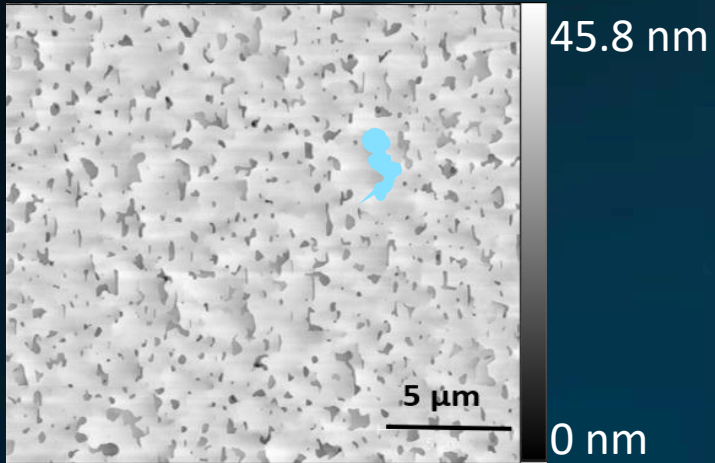
APD burying model

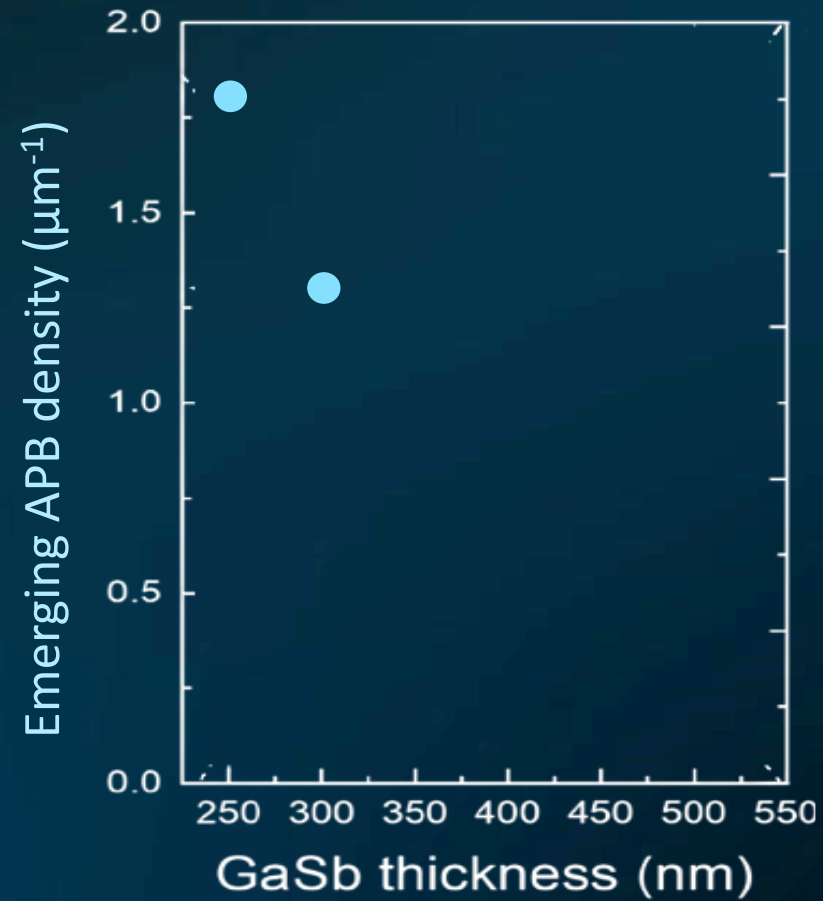
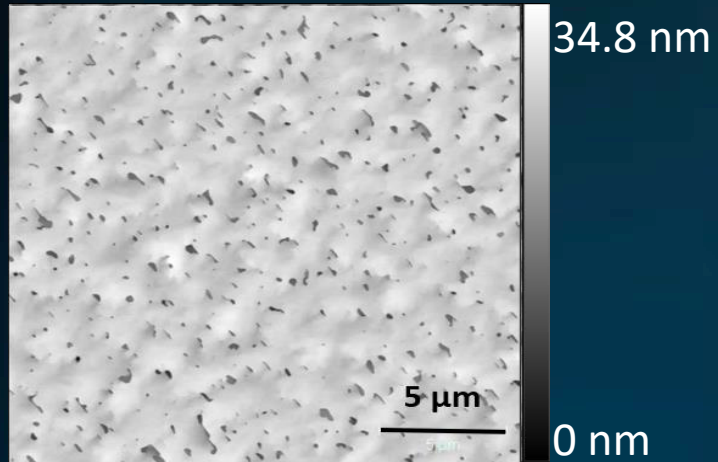
Step-flow



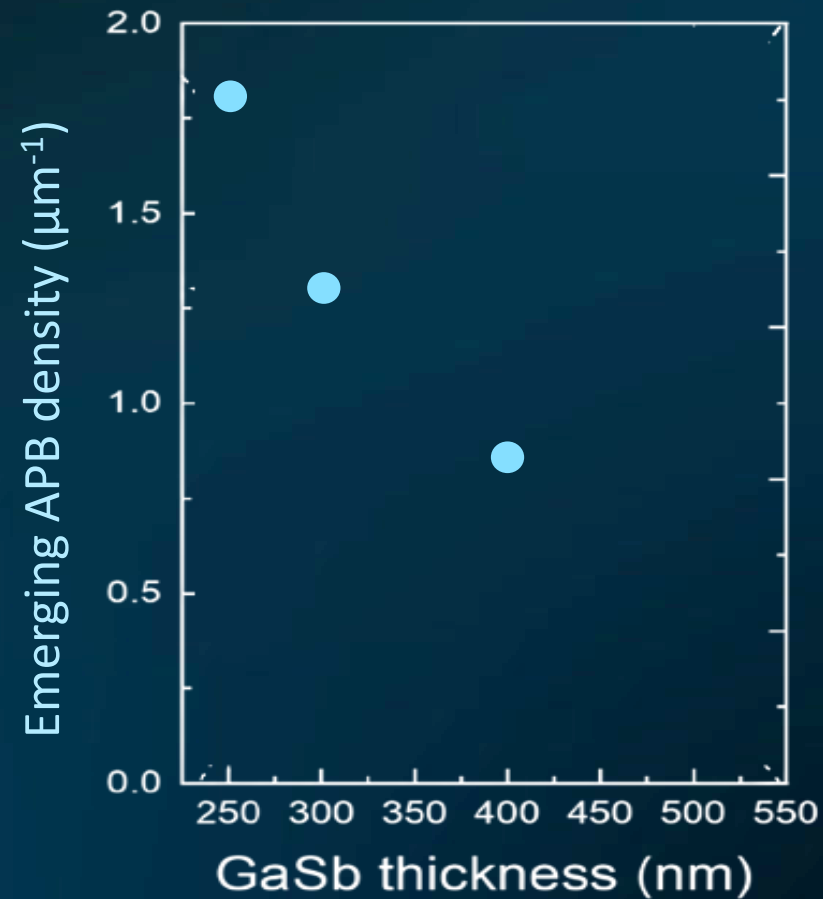
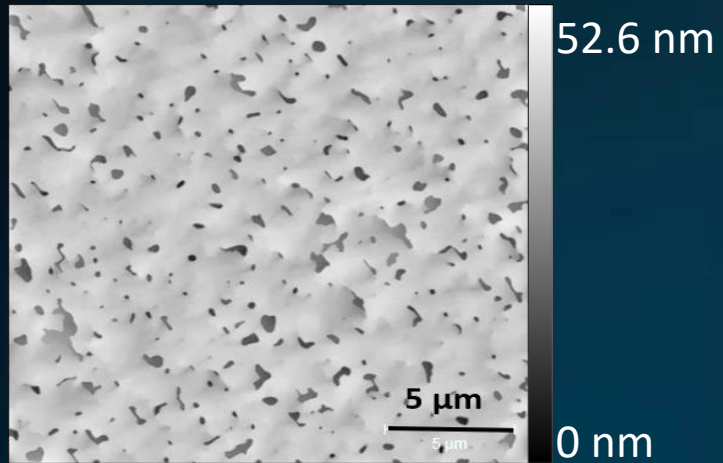
Growth rate imbalance:
One domain is buried because it grows slower

GaSb on Si APD burying

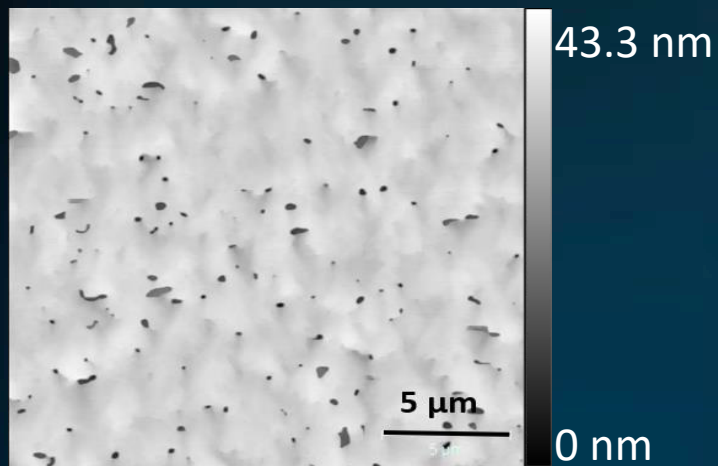




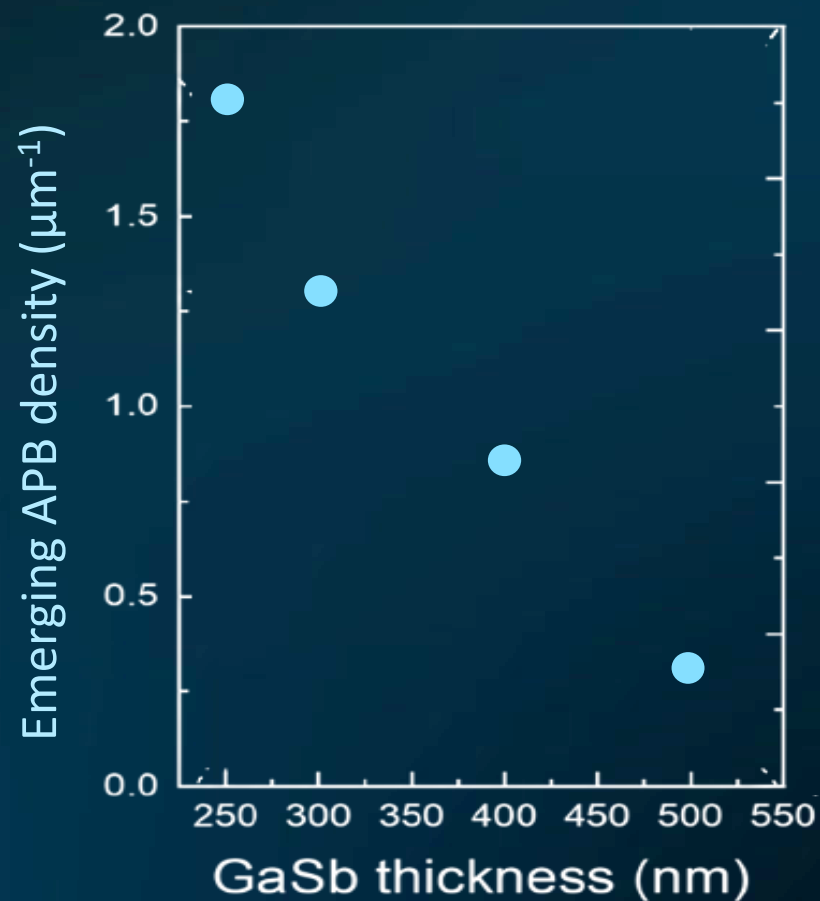
GaSb on Si APD burying



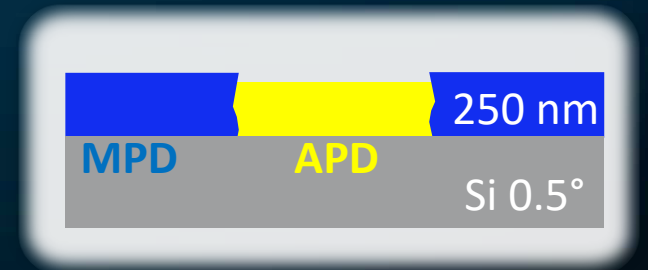
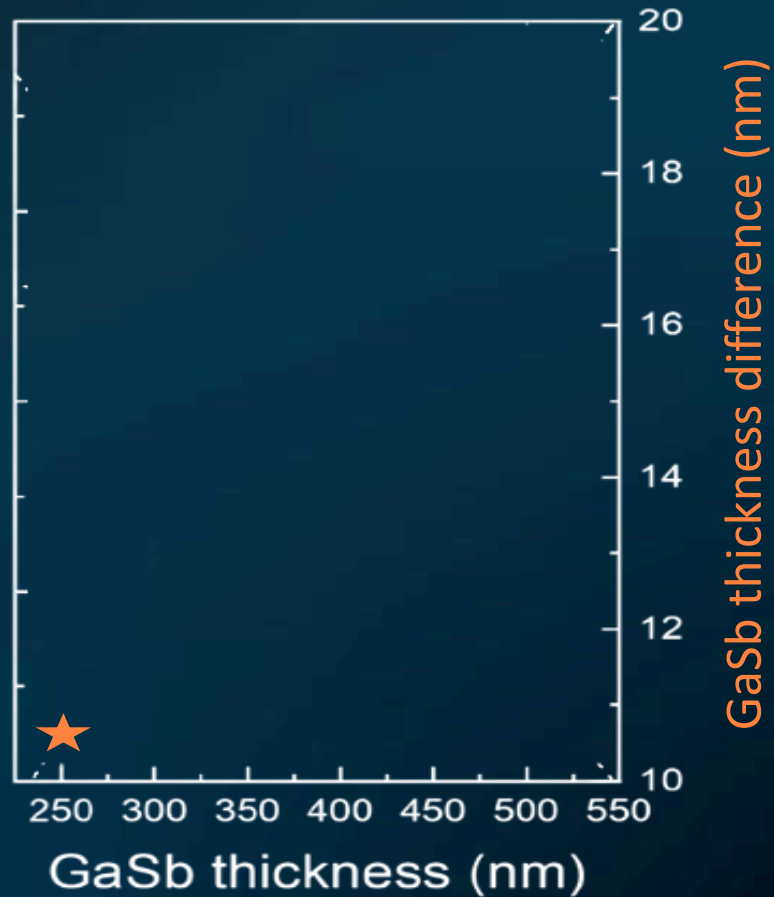
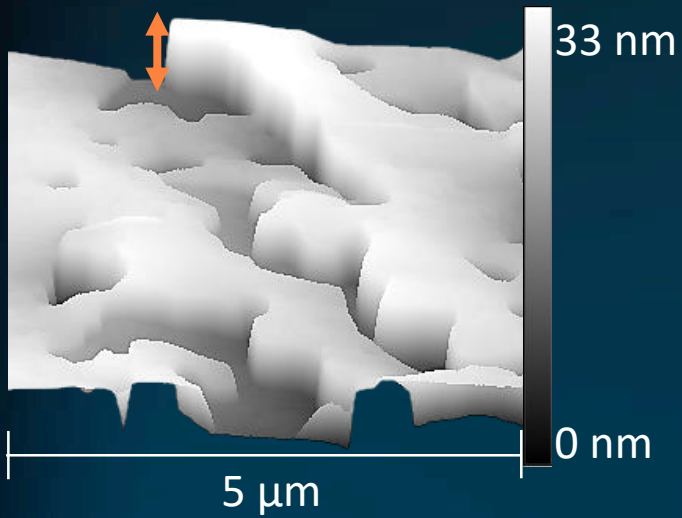
GaSb on Si APD burying



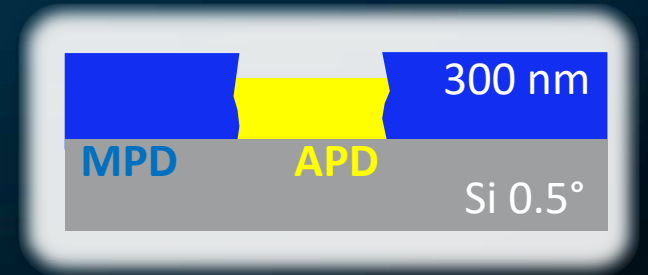
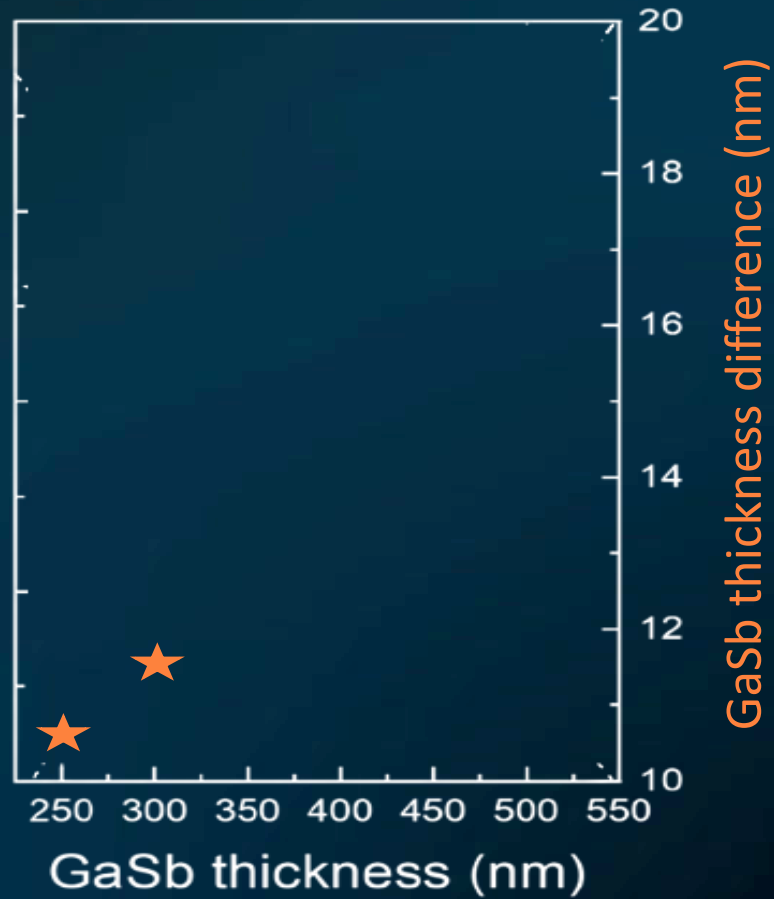
APB density ↓ :
buried at 550 nm



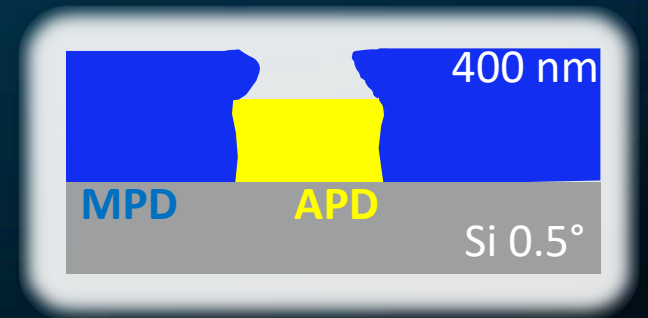
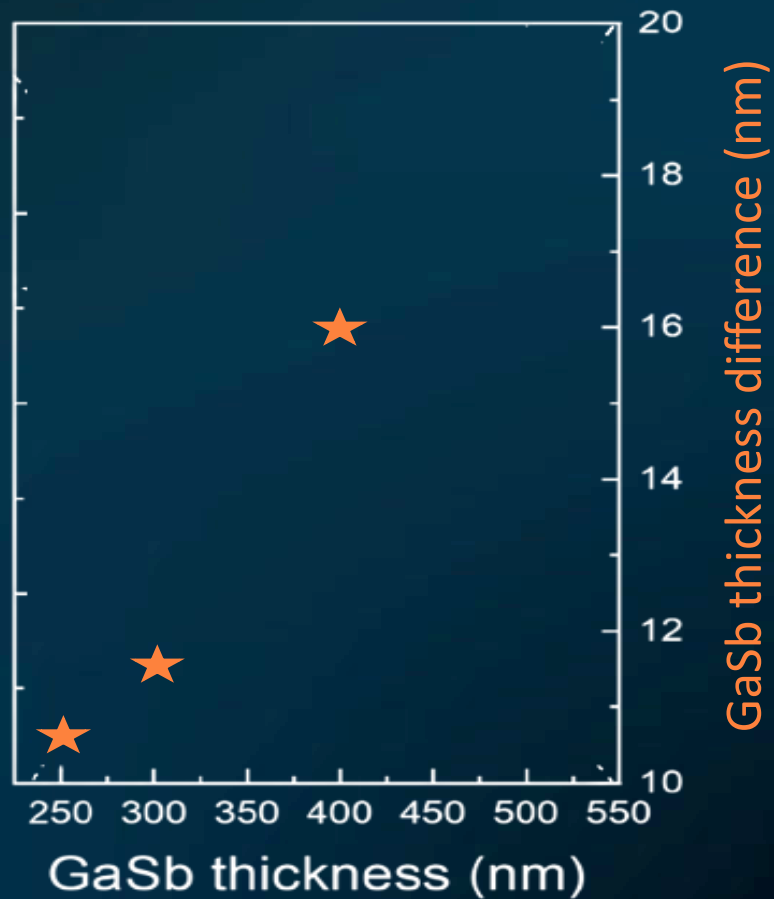
GaSb on Si APD burying



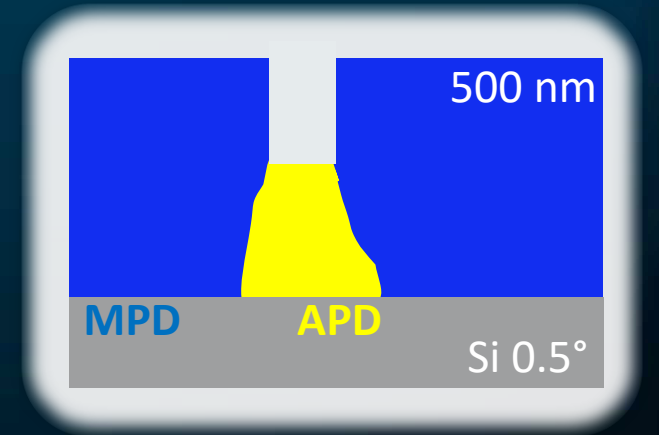
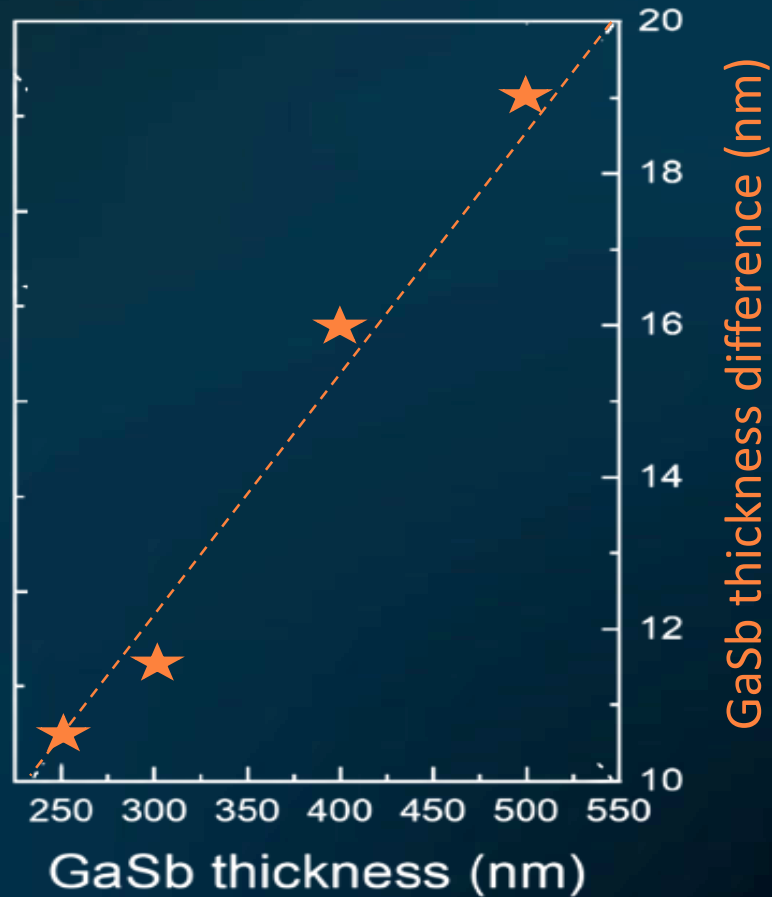
GaSb on Si APD burying



GaSb on Si APD burying

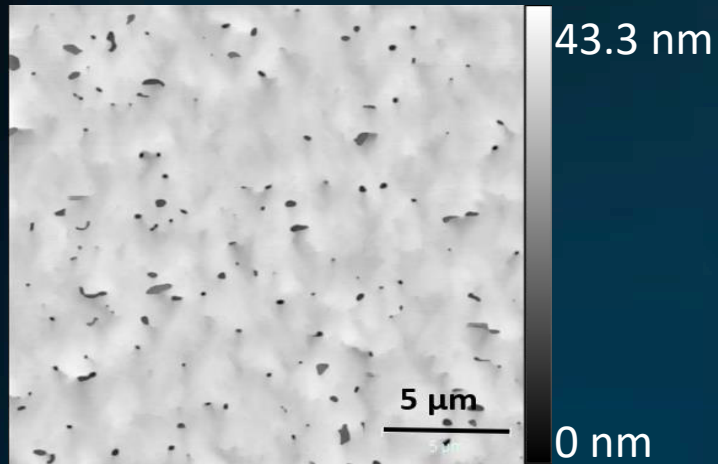


GaSb on Si APD burying

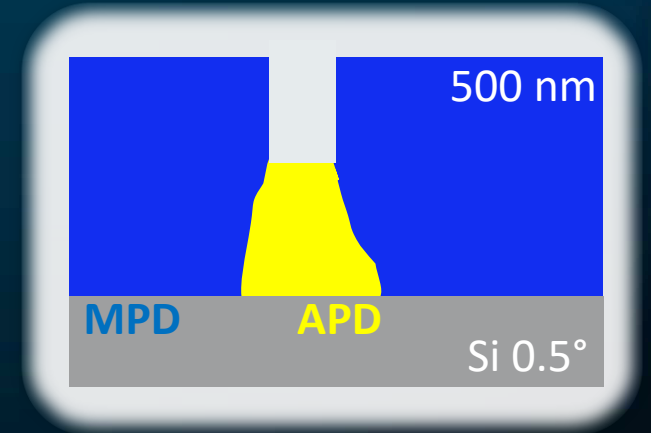
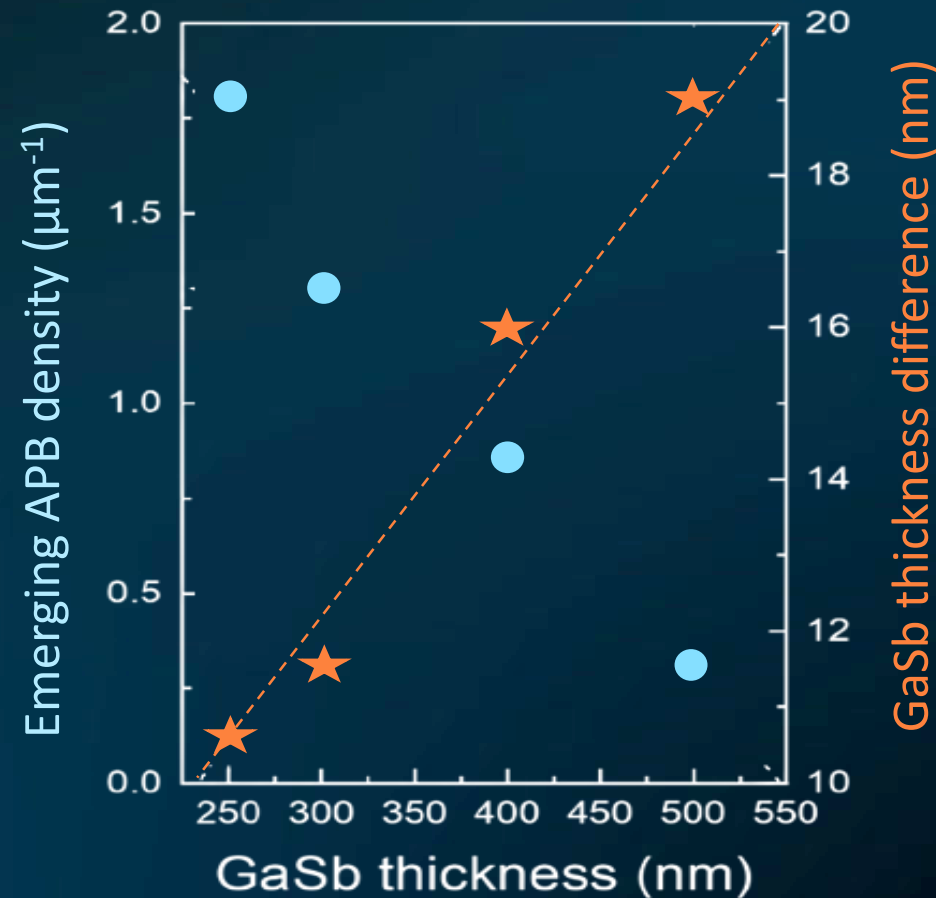


Depth difference \uparrow :
3% growth rate difference

GaSb on Si APD burying



APB density ↓ :
buried at 550 nm

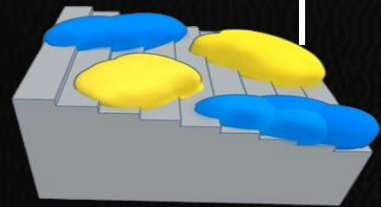
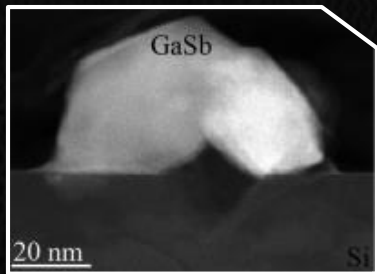


Depth difference ↑ :
3% growth rate difference

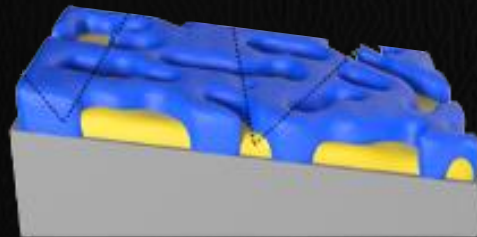
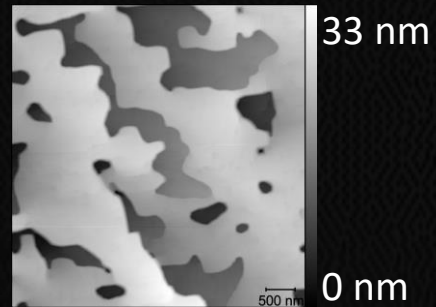
One domain grows slower and is buried

Universal burying

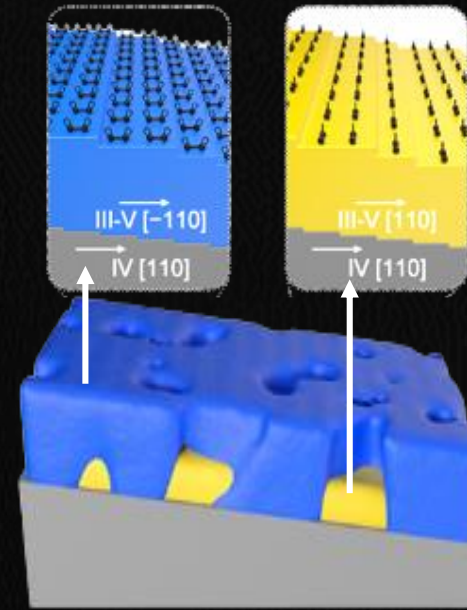
3D islands larger than Si monoatomic steps



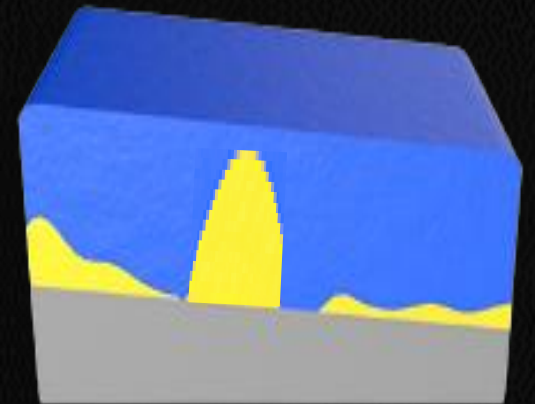
Coalescence of III and V-polar phases



V-polar phase grows 3% faster and overgrows the APD

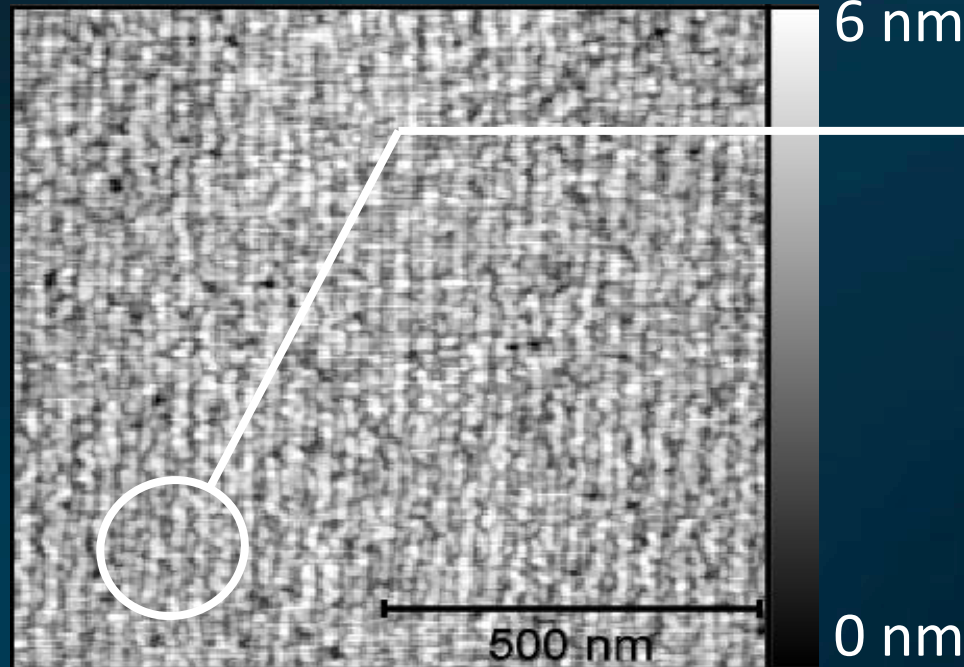
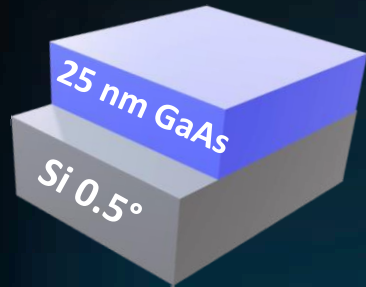


APD is buried

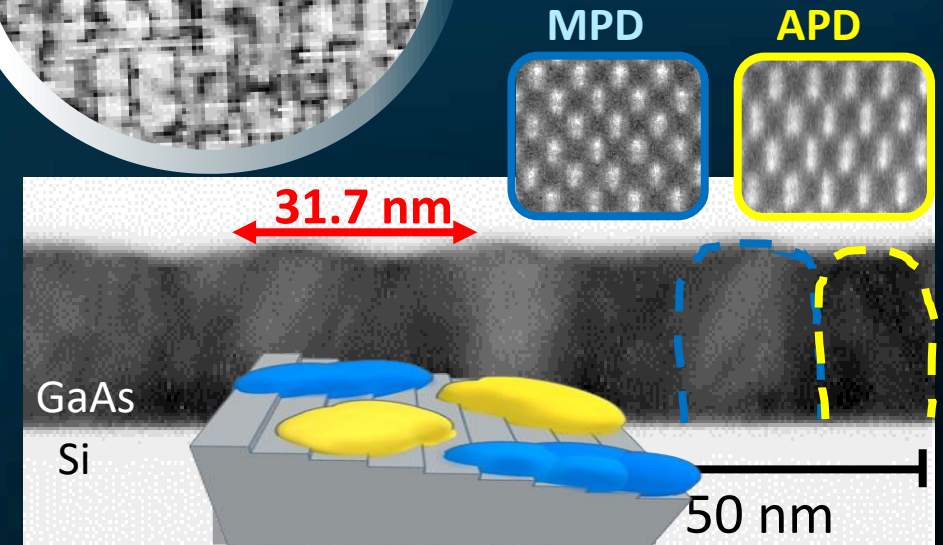
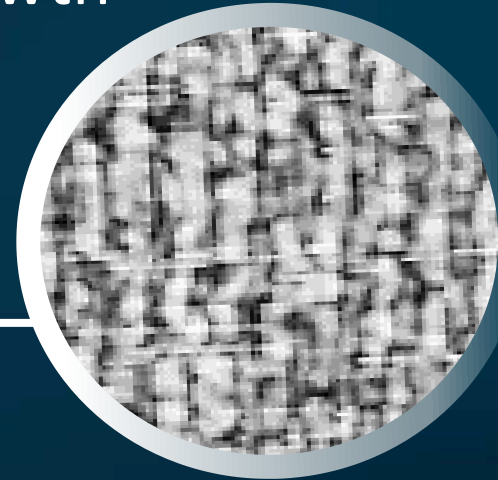


GaAs APBs burying

LOW T°C growth



Stripes alternation

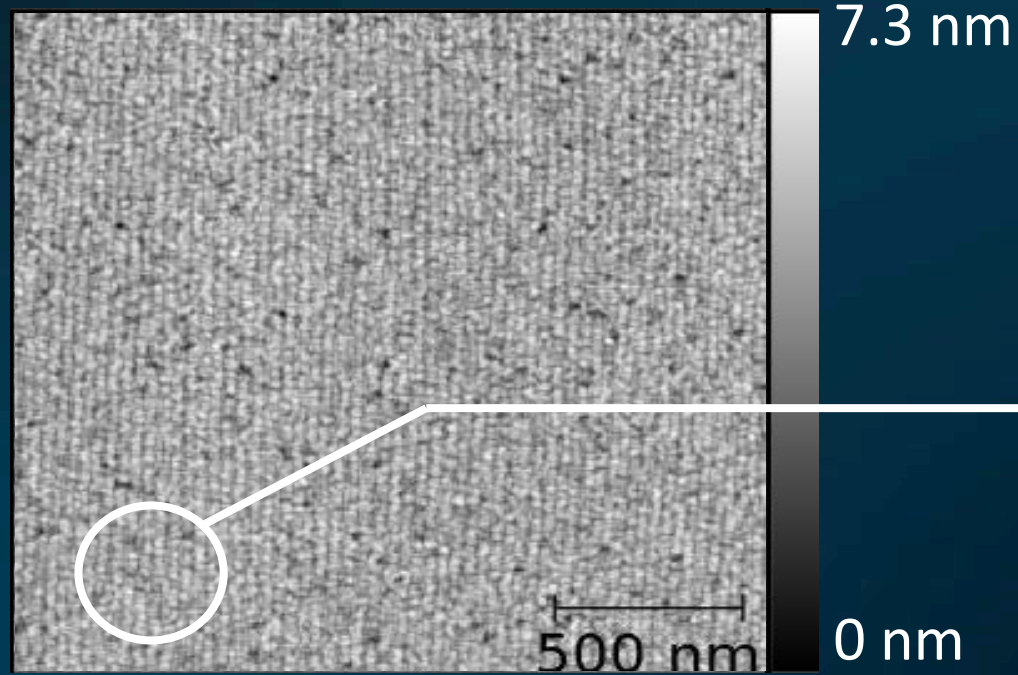


APD/MPD alternation

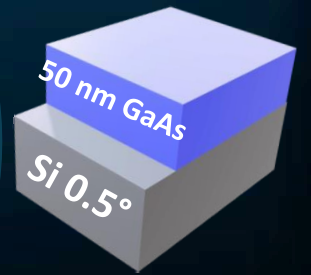
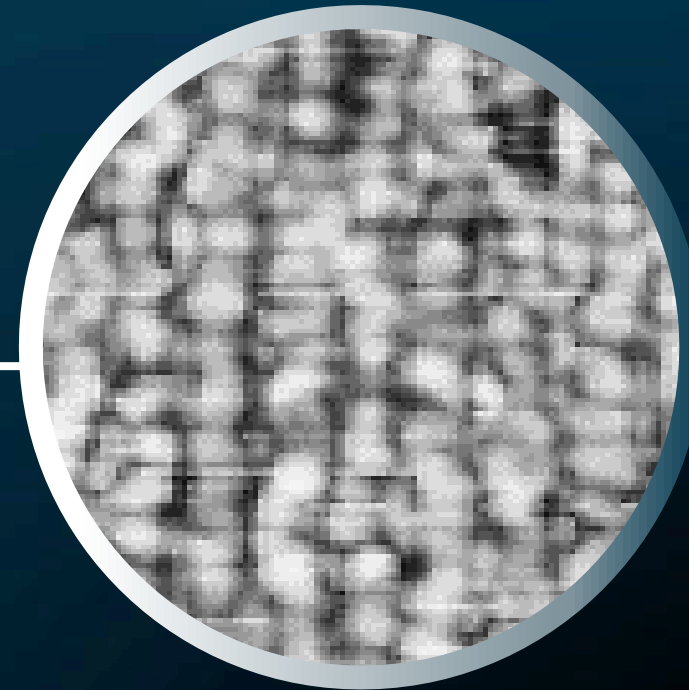
Domain width = mono-atomic terrace width

GaAs APBs burying

LOW T°C growth

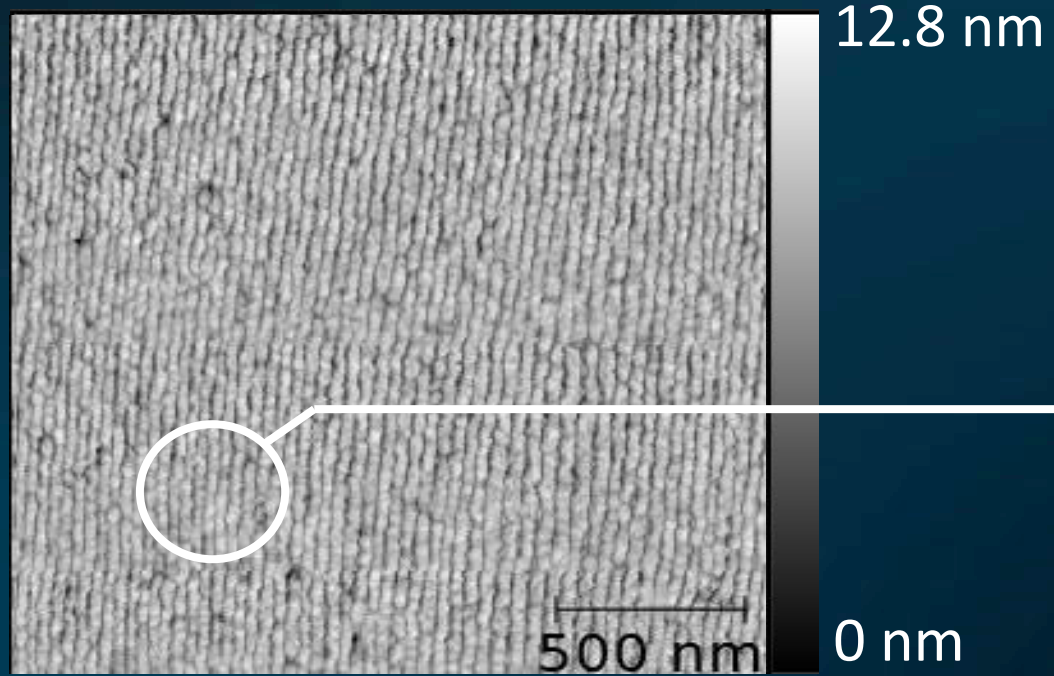


APD stripes shrinks

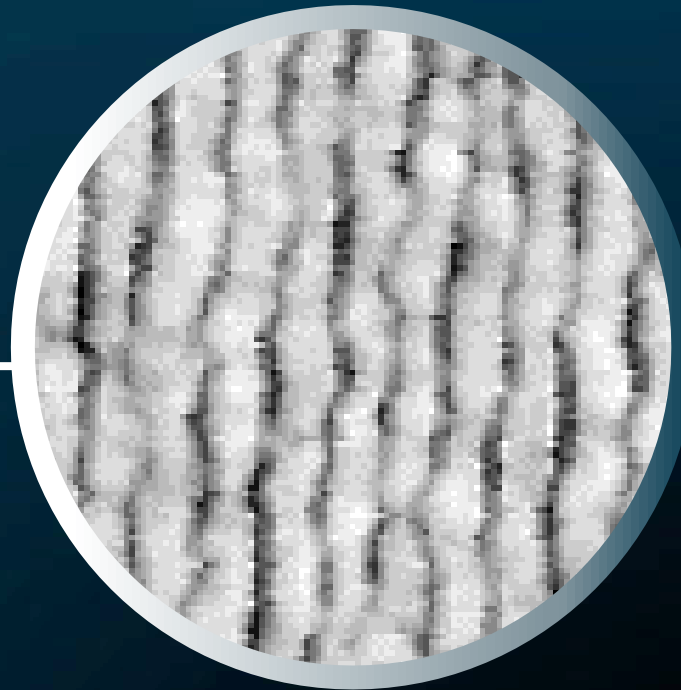


GaAs APBs burying

LOW T°C growth

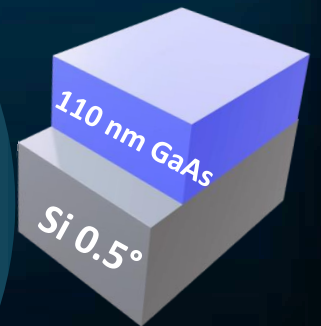
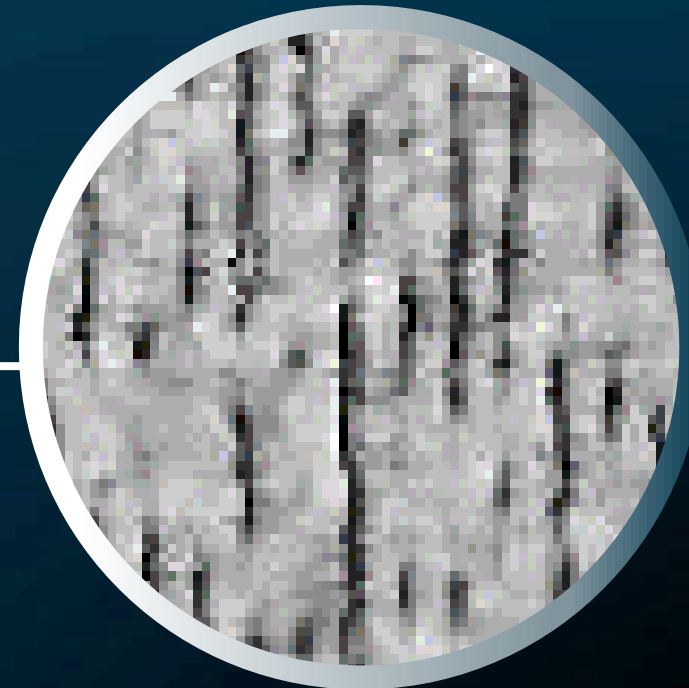
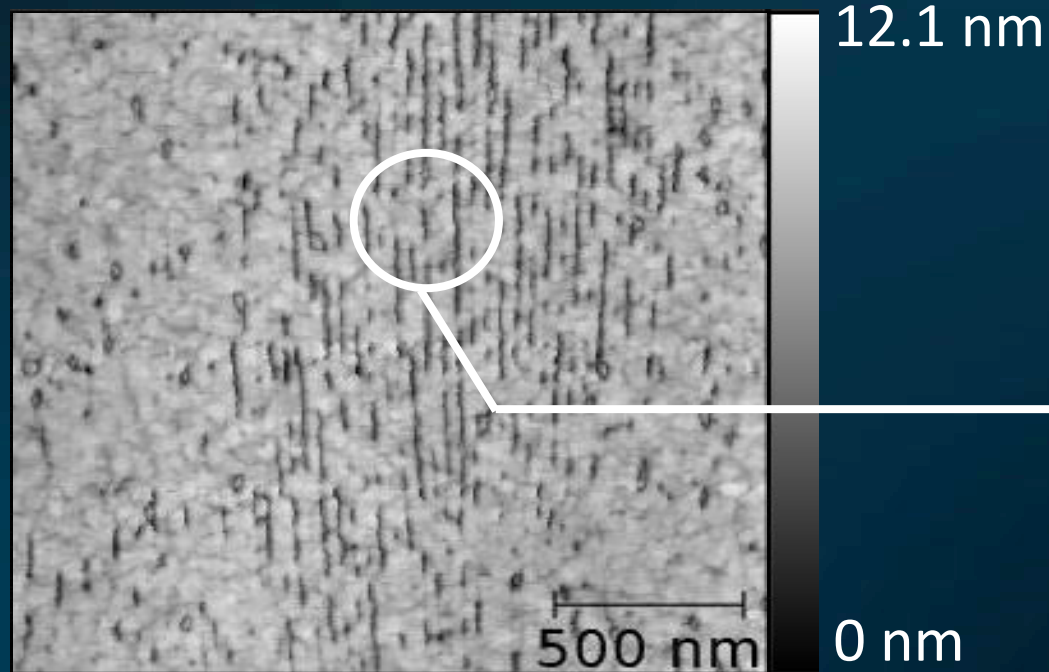


Lines



GaAs APBs burying

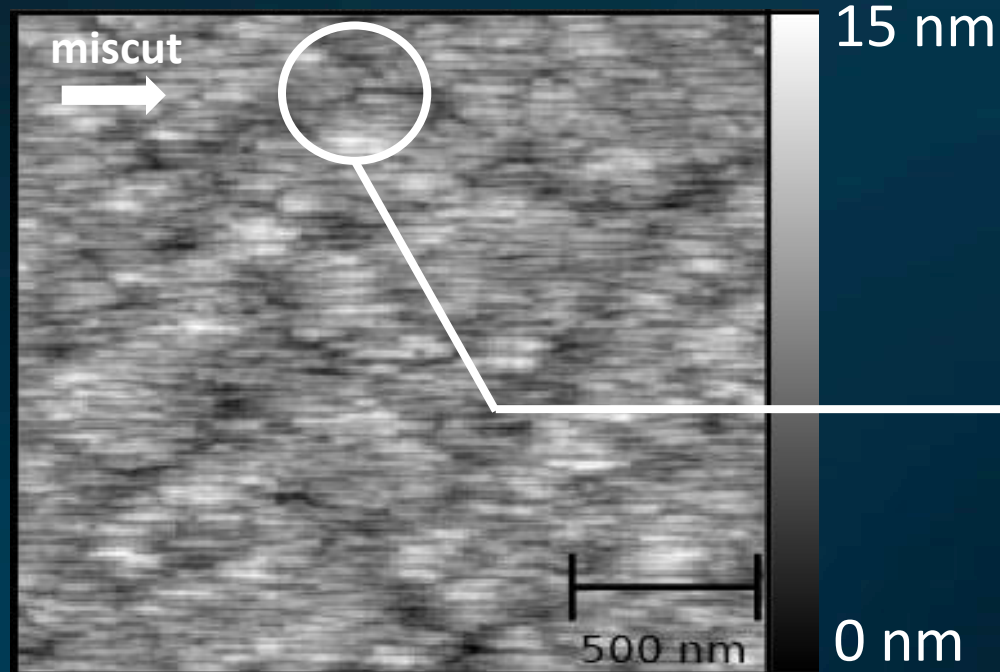
LOW T°C growth



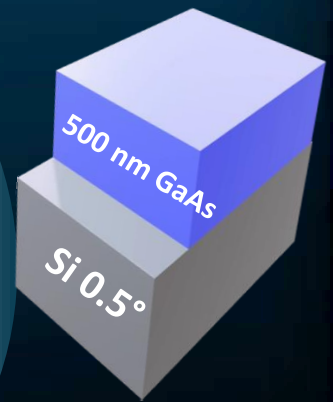
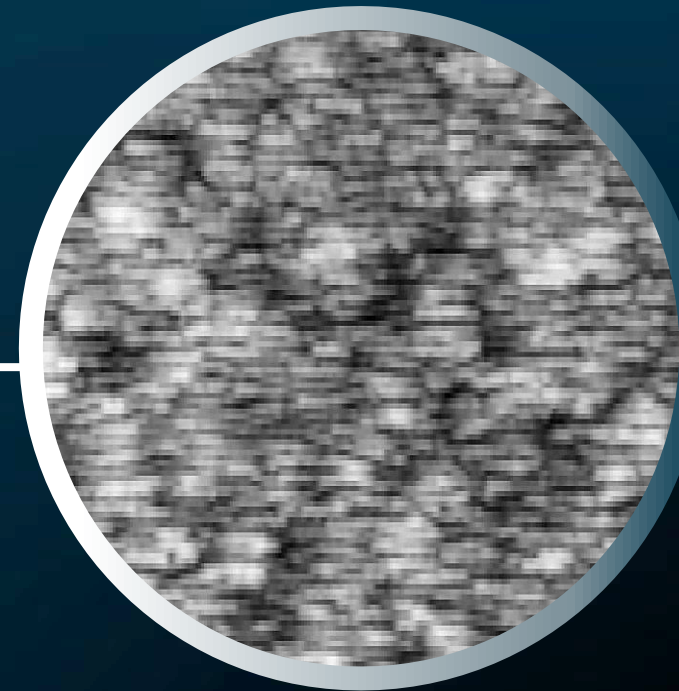
Lines disappear

GaAs APBs burying

100 nm LOW T°C + 400 nm MT°C



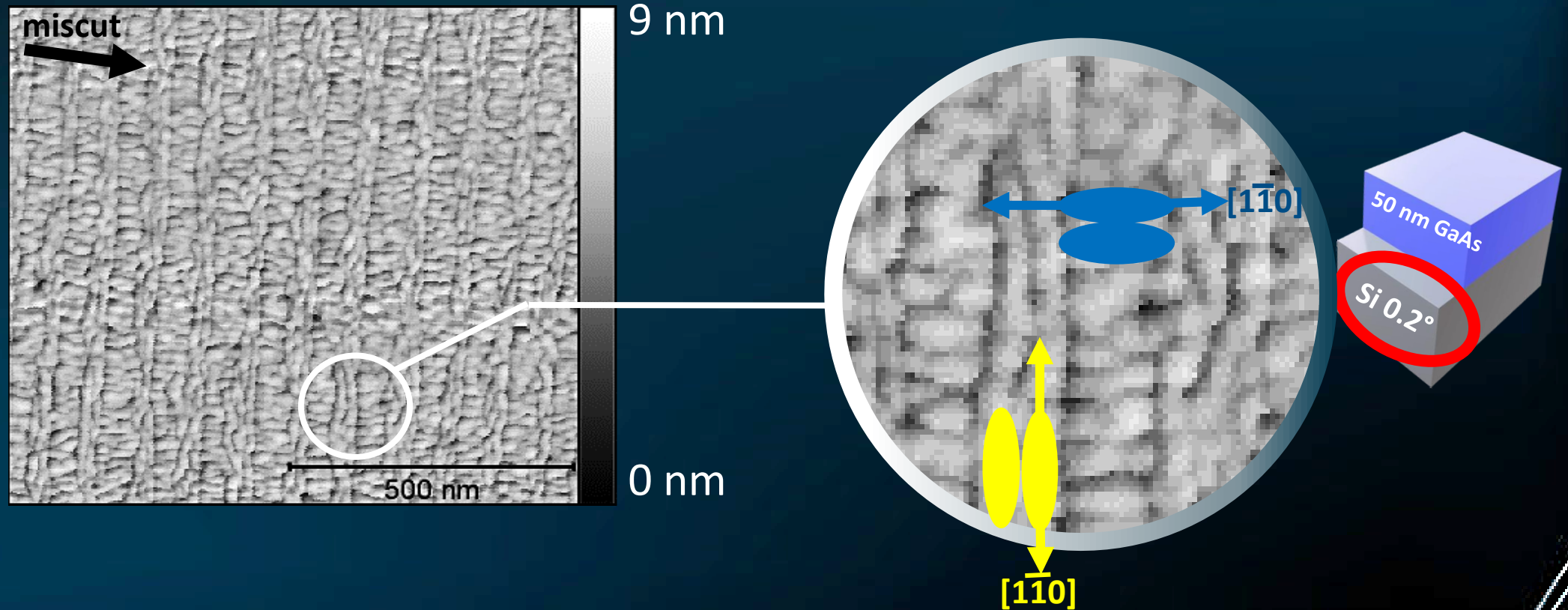
Elongated shapes // miscut



Different initial phase distribution + no step-flow

GaAs APBs burying

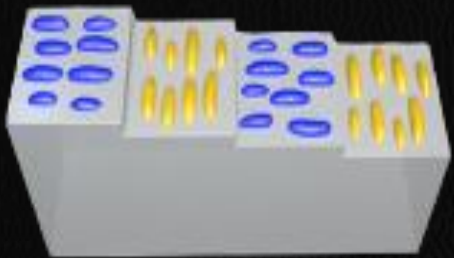
Islands grow faster in $[\bar{1}\bar{1}0]$ direction because of a difference in diffusion length



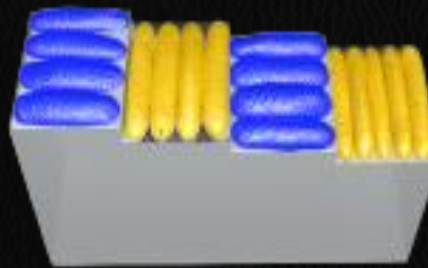
One phase expands faster towards the other

Universal burying

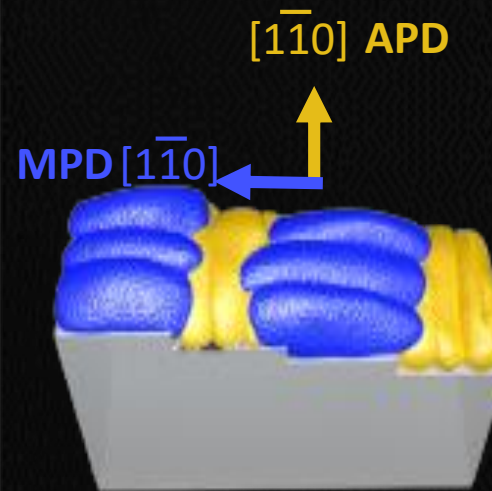
3D islands smaller than
Si monoatomic steps



Coalescence contained
in terraces:
Alternation APD/MPD



Faster growth in $[1\bar{1}0]$:
MPD overflows APD

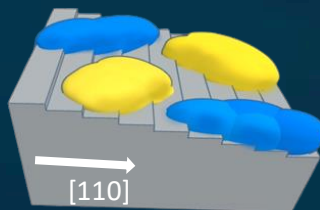
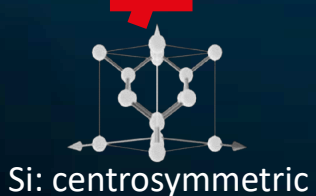


APD is buried



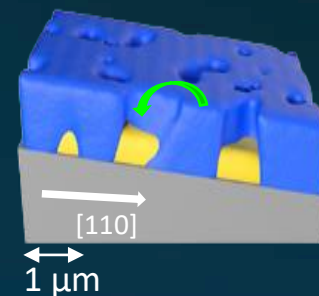
Summary

Lower symmetry of III-V: two phases



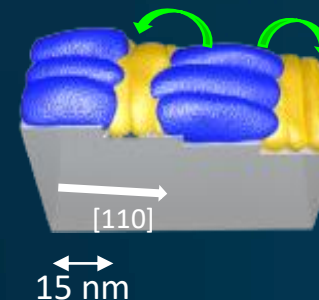
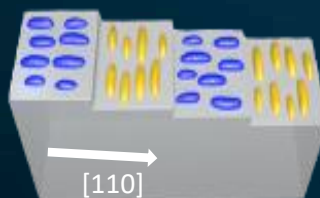
Miscut

transfer in $[1\bar{1}0]$ direction
breaks the symmetry

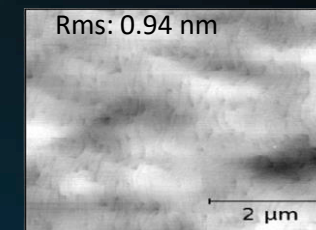


Anisotropy

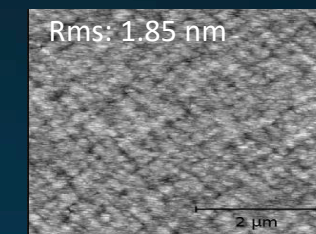
faster incorporation in V-steps
faster island elongation in $[110]$



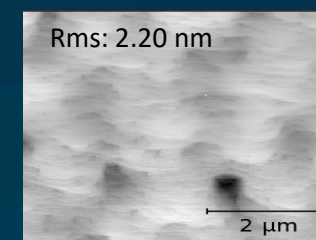
500 nm GaSb on Si 0.5°



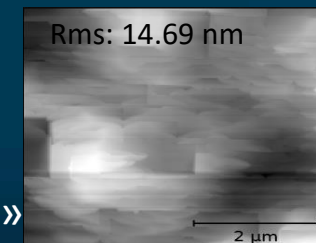
500 nm GaAs on Si 0.5°



500 nm GaSb on Ge 0.5°



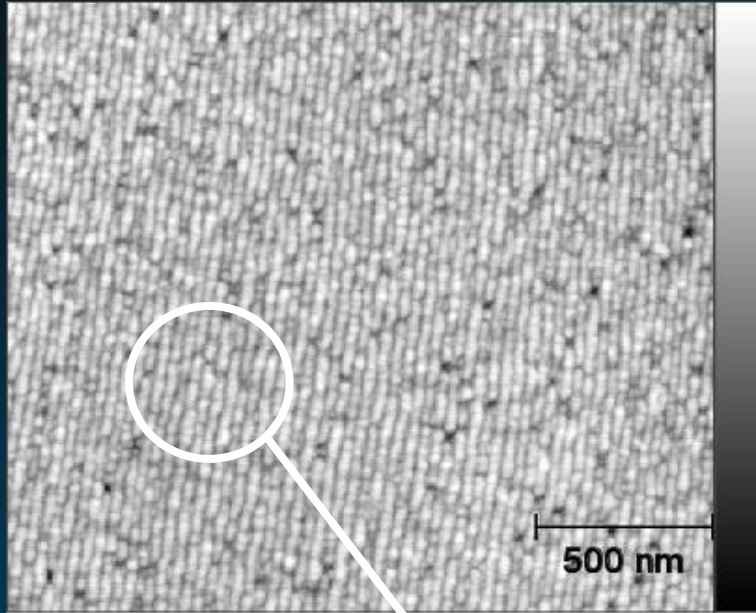
500 nm InAs on Ge 0.5°



Thank you for your attention

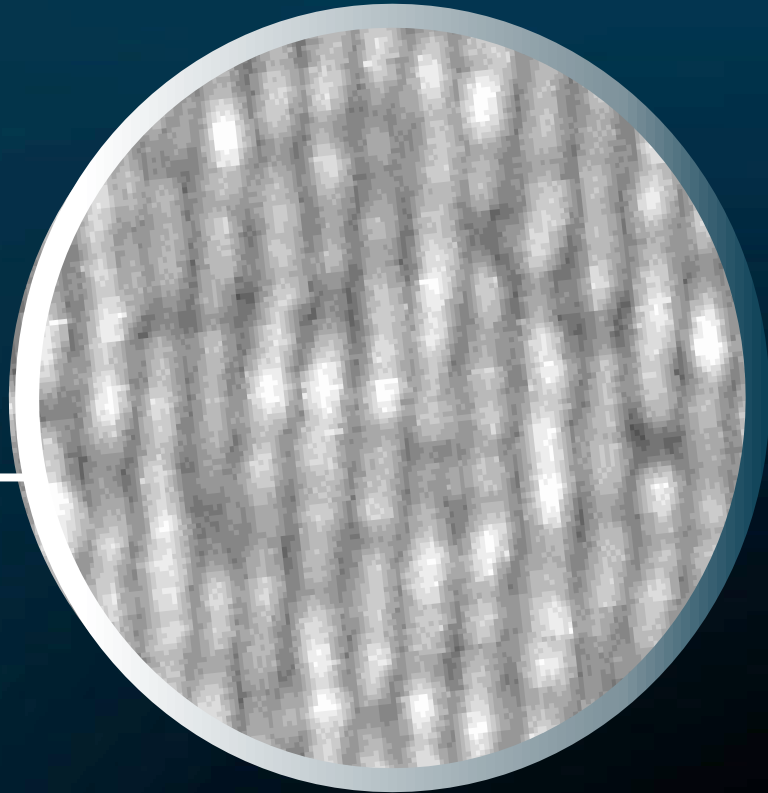
See M. Fagot's poster «ICLs à 3,3 μm sur substrats de GaSb, GaAs et Si (001)»

350°C



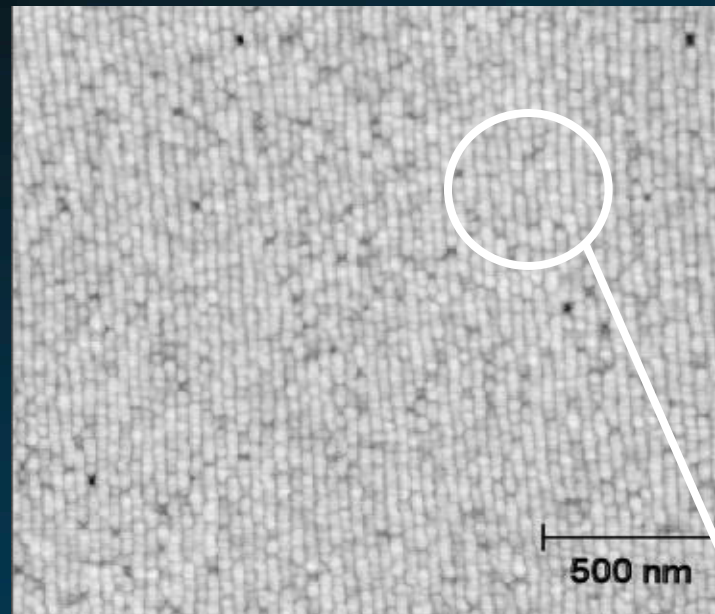
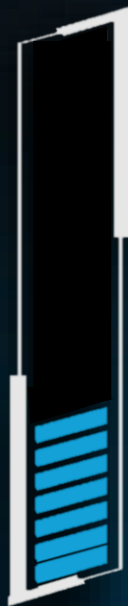
8 nm

0 nm



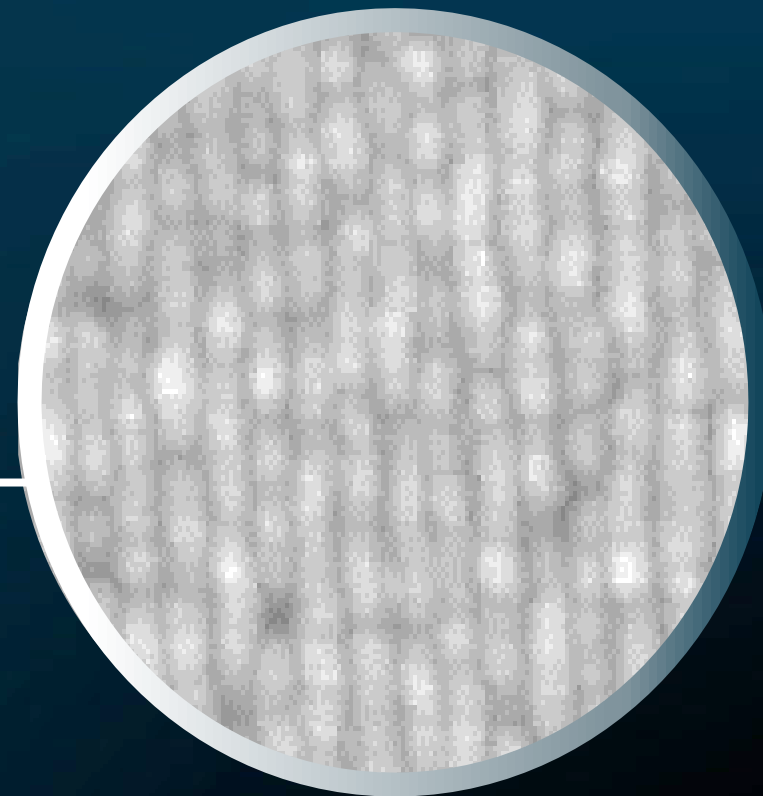
Stripes
Organization

400°C



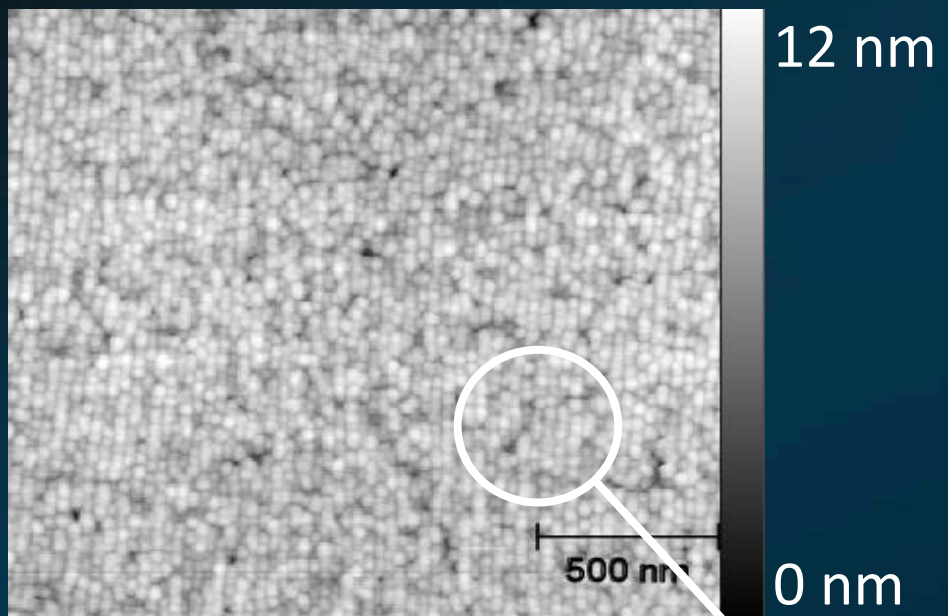
12 nm

0 nm

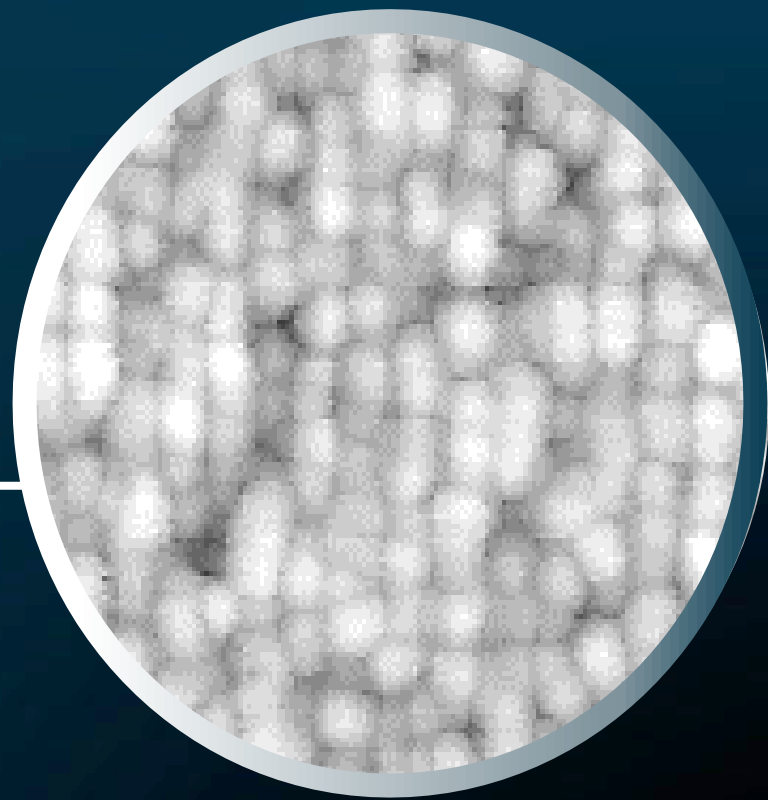


Stripes
Organization

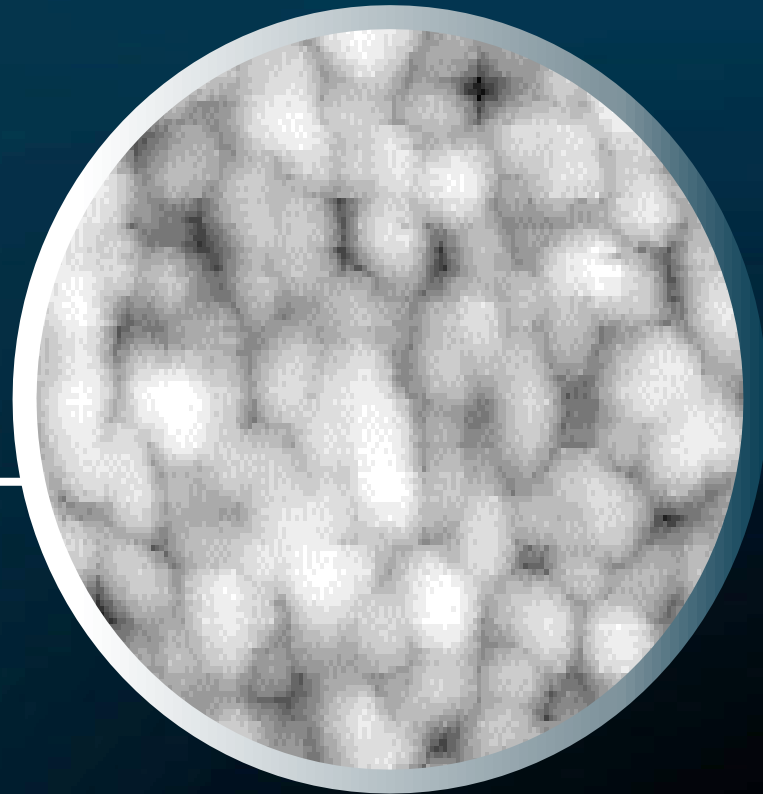
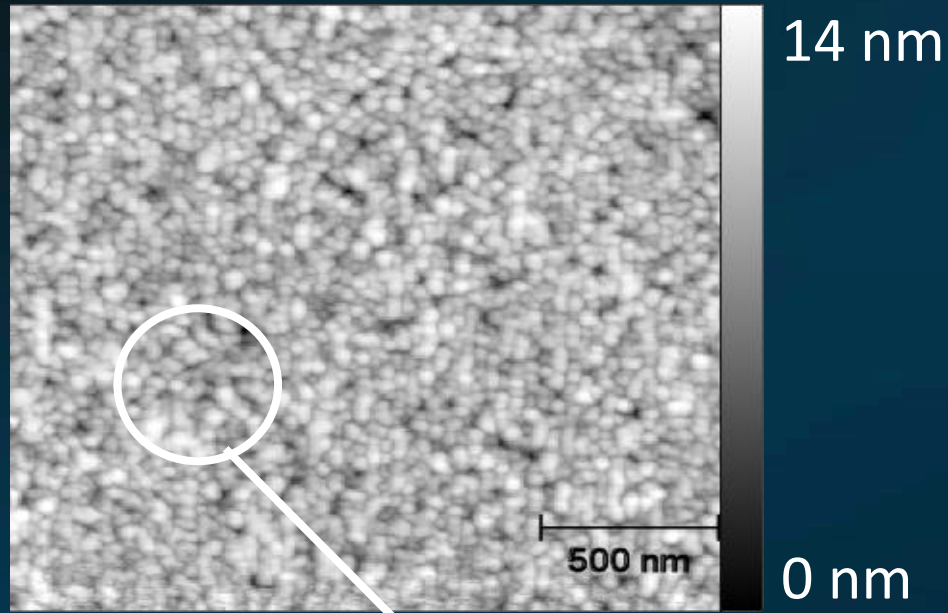
420°C



Stripes

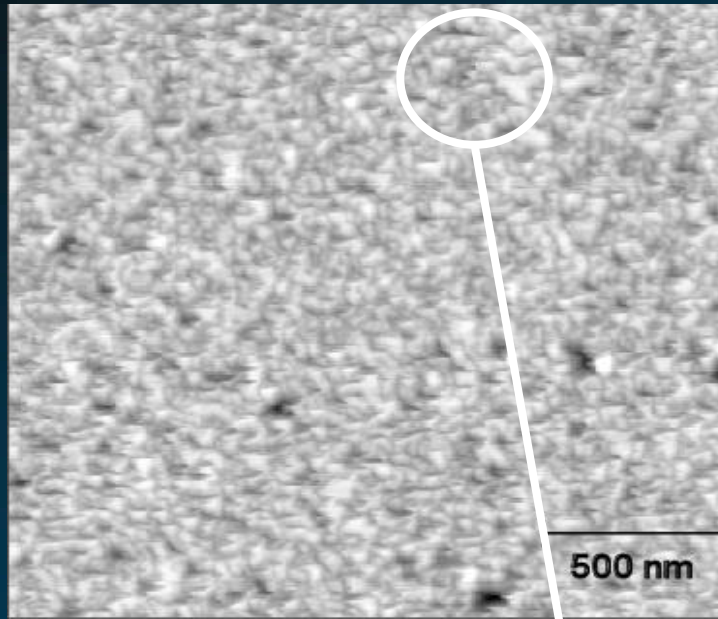


470°C



No stripes
No organization

520°C



24 nm

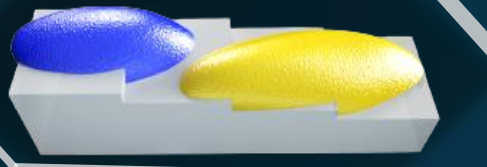
0 nm



No stripes
No organization

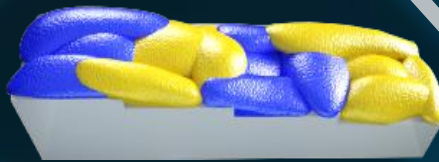
Regime transition

520°C



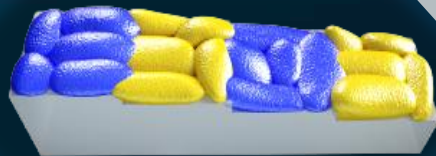
Stable island size > Si terraces

470°C



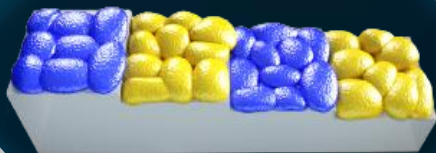
Nucleation-driven

420°C



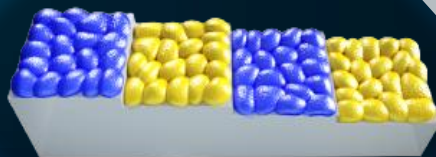
Stable island size < Si terraces

370°C



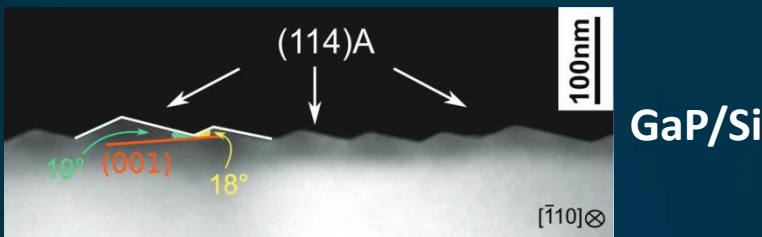
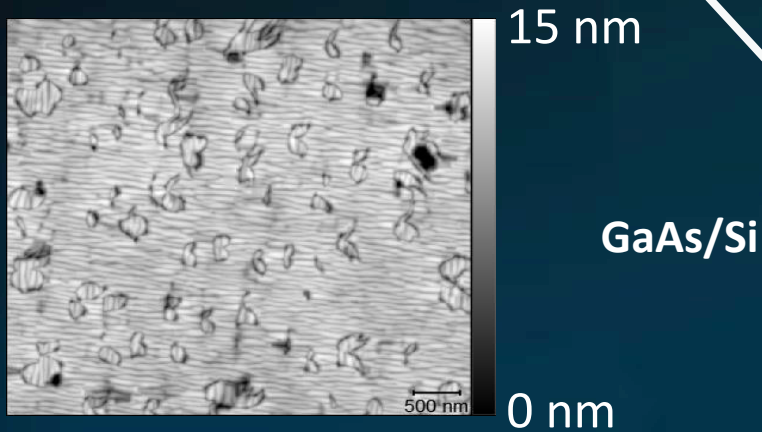
Terrace-driven

350°C



What could go wrong?

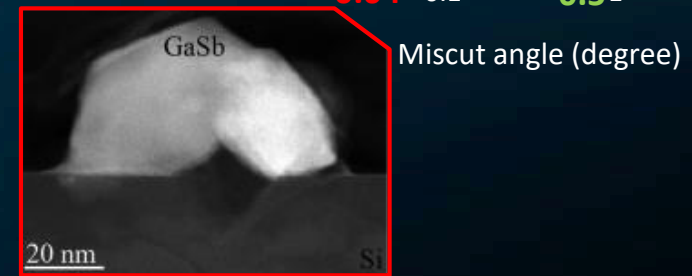
Y. B. Bolkhovityanov and O. P. Pchelyakov, Phys.-Uspekhi 51, 437 (2008)



Adv. Funct. Mater. 2018, 1801585; doi: 10.1002/adfm.201801585

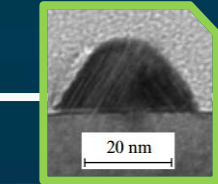
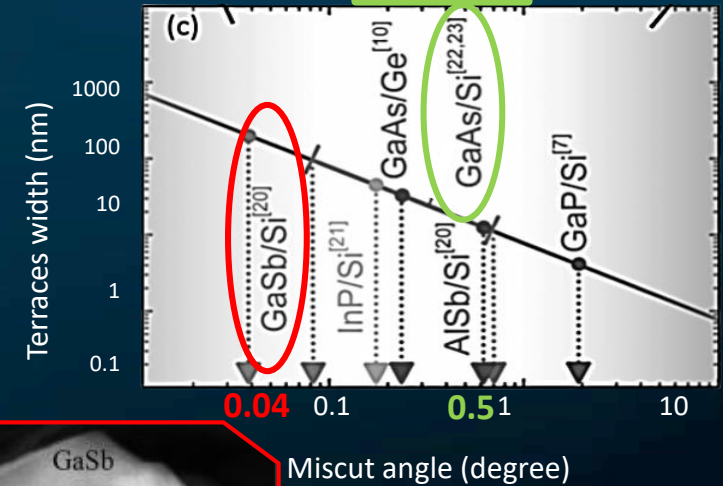
Facets impede step-flow

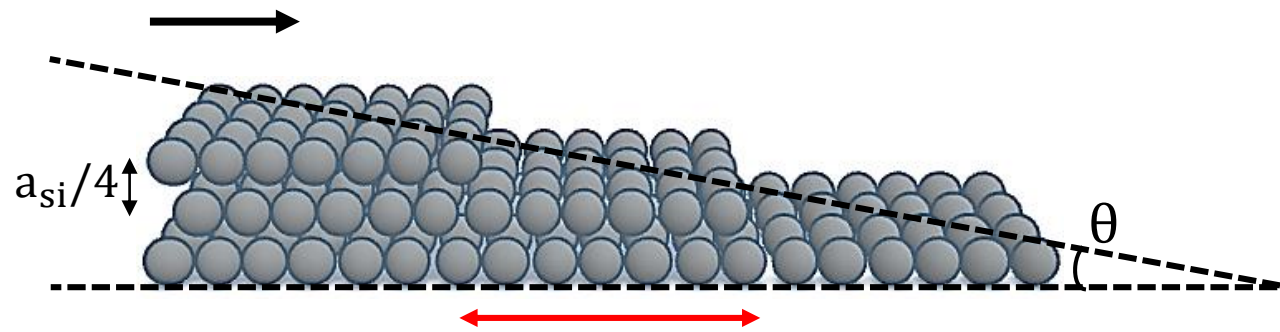
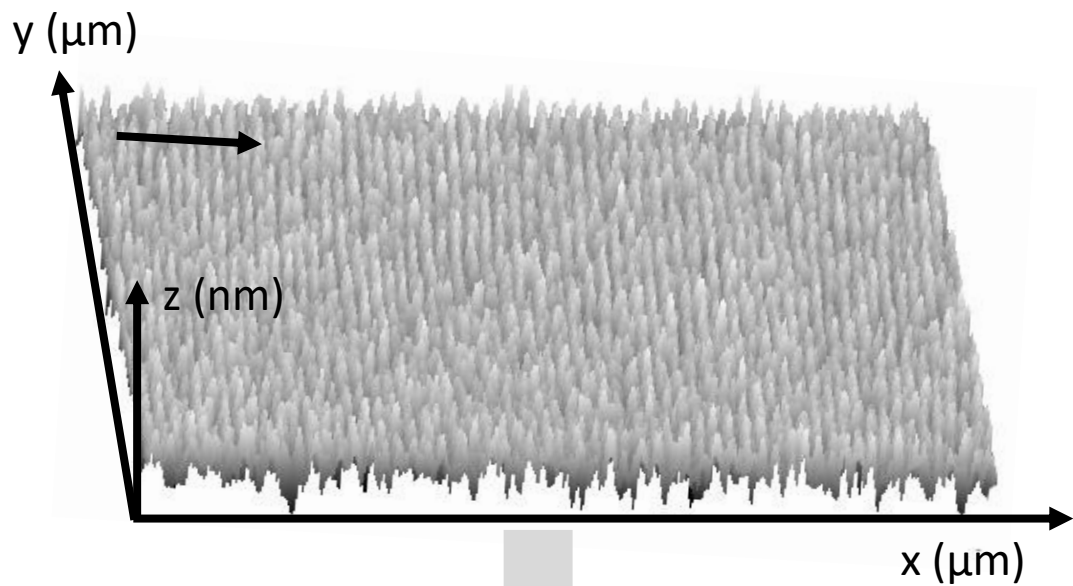
III-V not adapted /
limits of the
experiment



J. Appl. Phys. 114, 113101 (2013); doi: 10.1063/1.4820255

Initial islands too large





$$L = \frac{a_{\text{Si}}}{(4 \times \tan(\theta))} = 15.5 \text{ nm}$$

