

Low temperature PLD-growth of ZnO nanowires

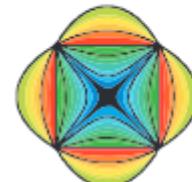
Alexander Shkurmanov

Chris Sturm

Helena Franke

Marius Grundmann

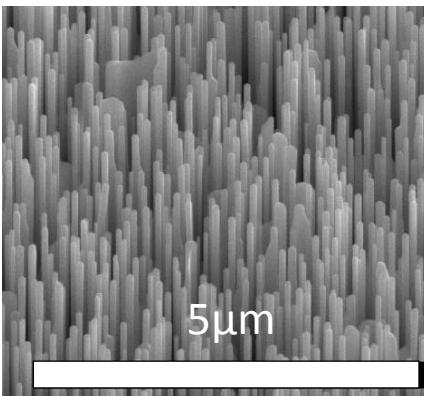
UNIVERSITÄT LEIPZIG



Semiconductor
Physics Group

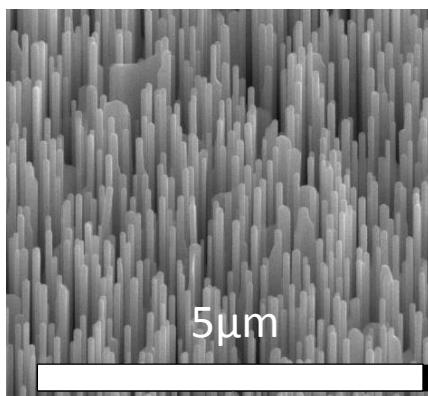
TG
2014

Motivation

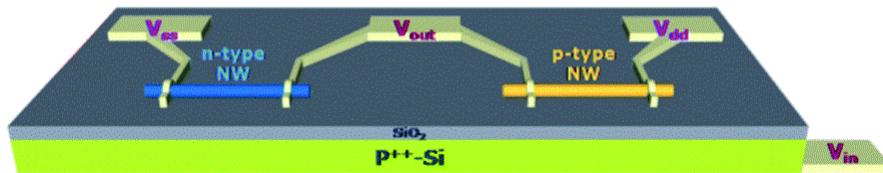


ZnO nanowires
on pure a-plane
sapphire

Motivation

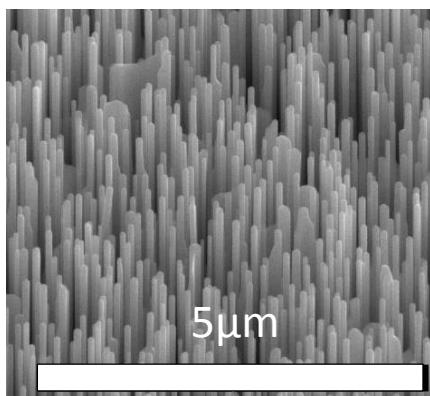


ZnO nanowires
on pure a-plane
sapphire



N.Van, et al: High performance Si nanowire field-effect-transistors based on a CMOS inverter with tunable threshold voltage, Nanoscale 6, 5479(2014)

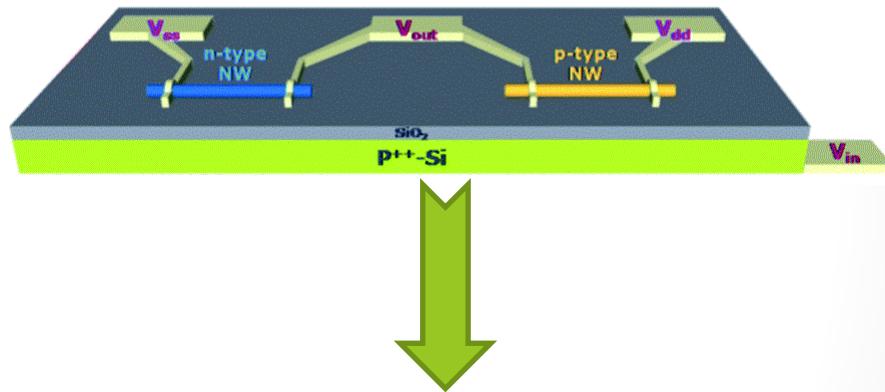
Motivation



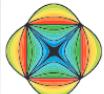
ZnO nanowires
on pure a-plane
sapphire



N.Van, et al: High performance Si nanowire field-effect-transistors based on a CMOS inverter with tunable threshold voltage, Nanoscale 6, 5479(2014)



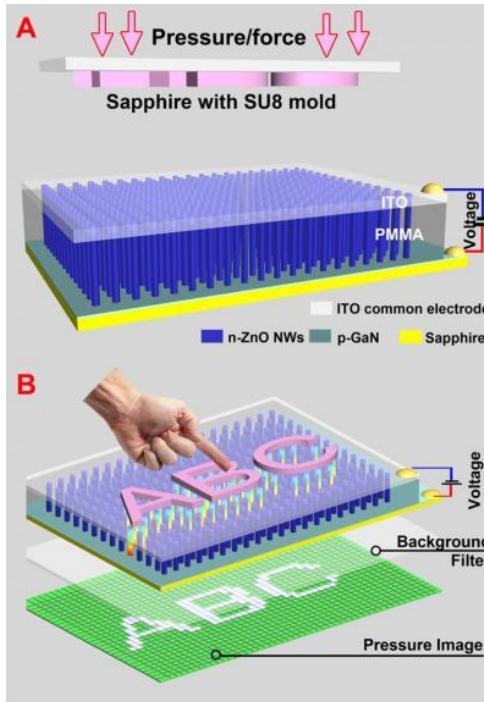
Devices based on the CMOS-structures



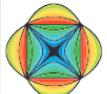
Motivation

Devices based on the CMOS-structures

- Pressure distribution



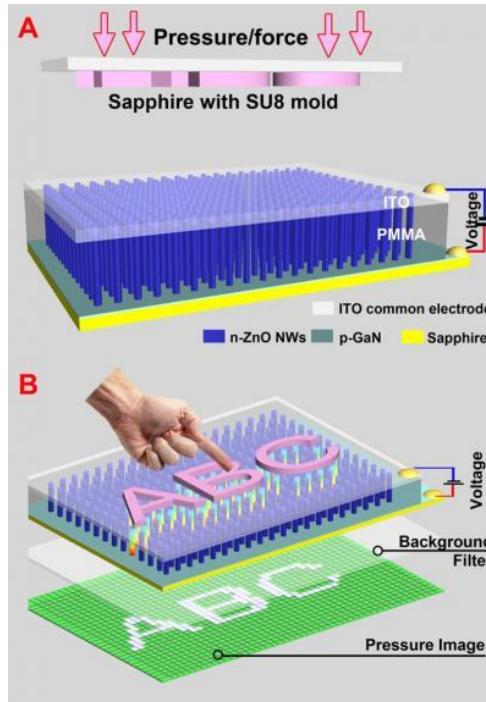
C.Pan, et al: High-resolution electroluminescent imaging of pressure distribution using a piezoelectric nanowire LED array, Nature Photonics 7, 752(2013)



Motivation

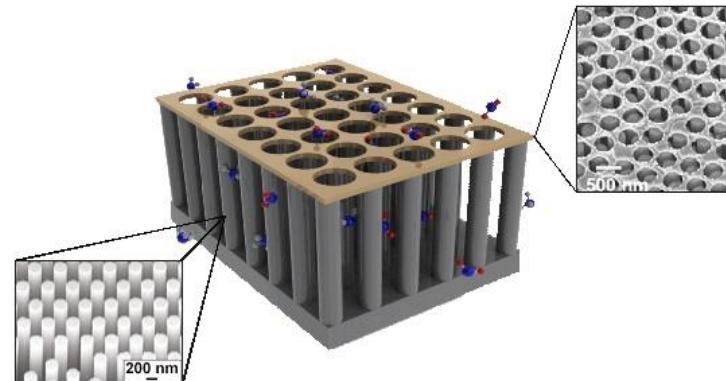
Devices based on the CMOS-structures

- Pressure distribution

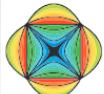


C.Pan, et al: High-resolution electroluminescent imaging of pressure distribution using a piezoelectric nanowire LED array, Nature Photonics 7, 752(2013)

- Gas sensor



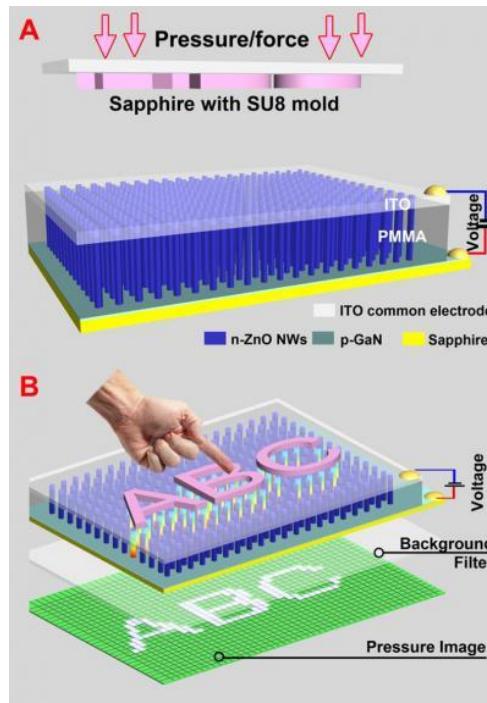
Christopher R. Field, et al: Vapor Detection Performance of Vertically Aligned, Ordered Arrays of Silicon Nanowires with a Porous Electrode."Analytical Chemistry 83, 4724 (2011).



Motivation

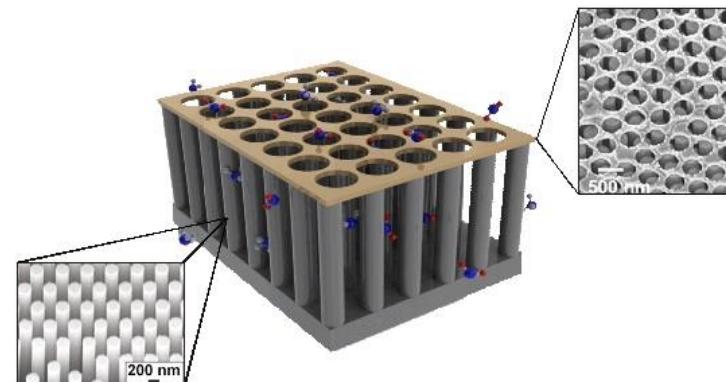
Devices based on the CMOS-structures

- Pressure distribution



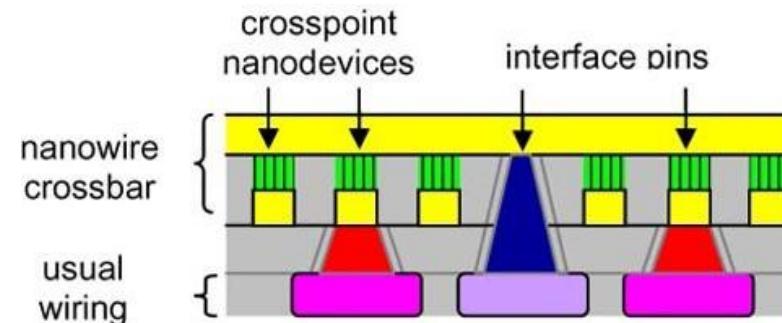
C.Pan, et al: High-resolution electroluminescent imaging of pressure distribution using a piezoelectric nanowire LED array, Nature Photonics 7, 752(2013)

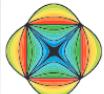
- Gas sensor



Christopher R. Field, et al: Vapor Detection Performance of Vertically Aligned, Ordered Arrays of Silicon Nanowires with a Porous Electrode."Analytical Chemistry 83, 4724 (2011).

- Mixed-signal neuromorphic networks

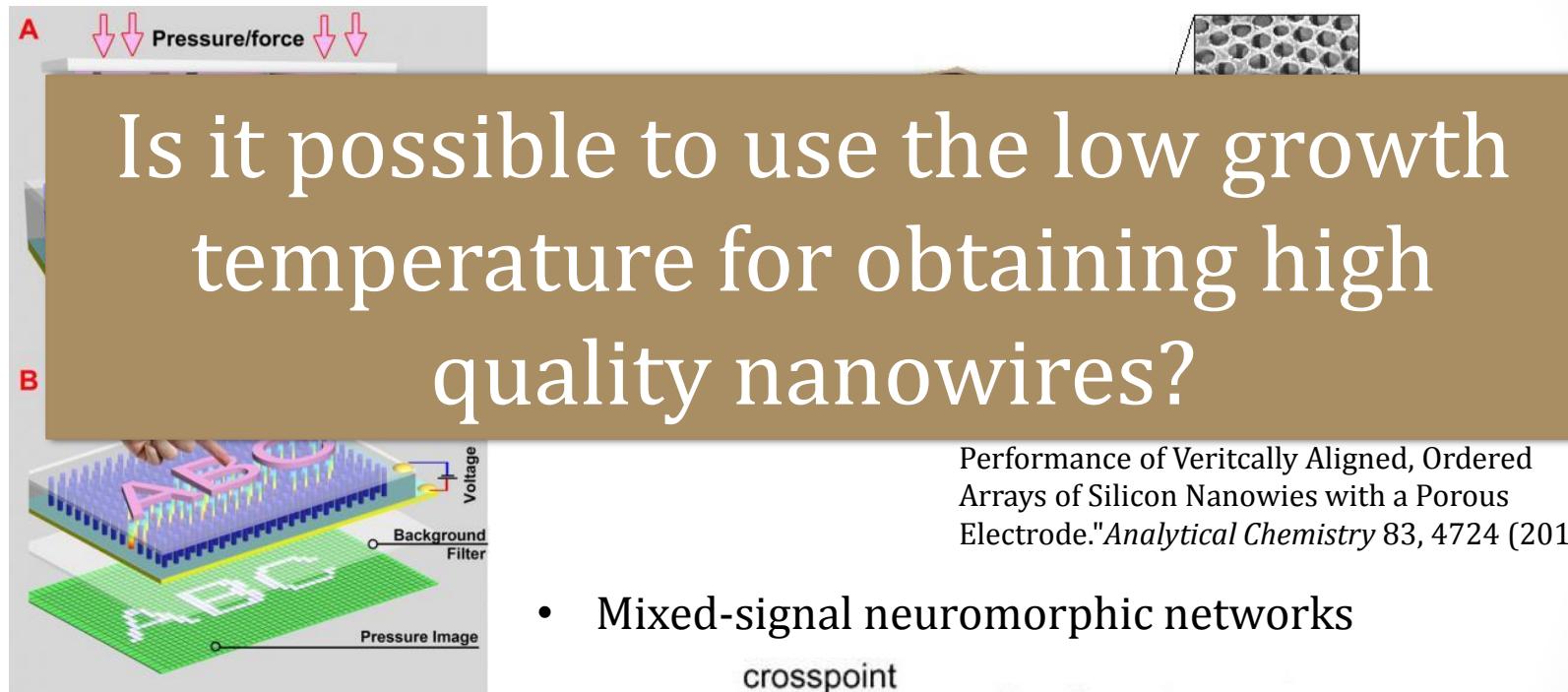




Motivation

Devices based on the CMOS-structures

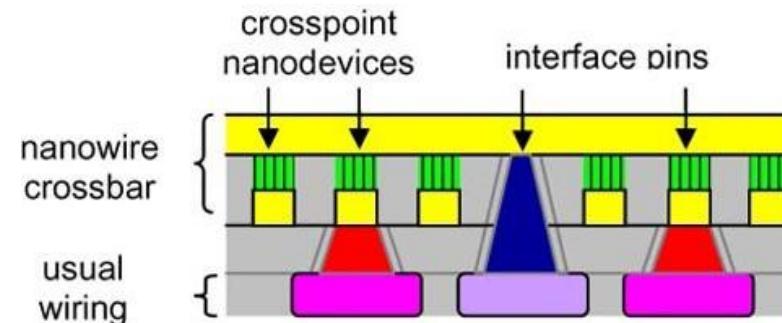
- Pressure distribution
- Gas sensor

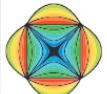


C.Pan, et al: High-resolution electroluminescent imaging of pressure distribution using a piezoelectric nanowire LED array, Nature Photonics 7, 752(2013)

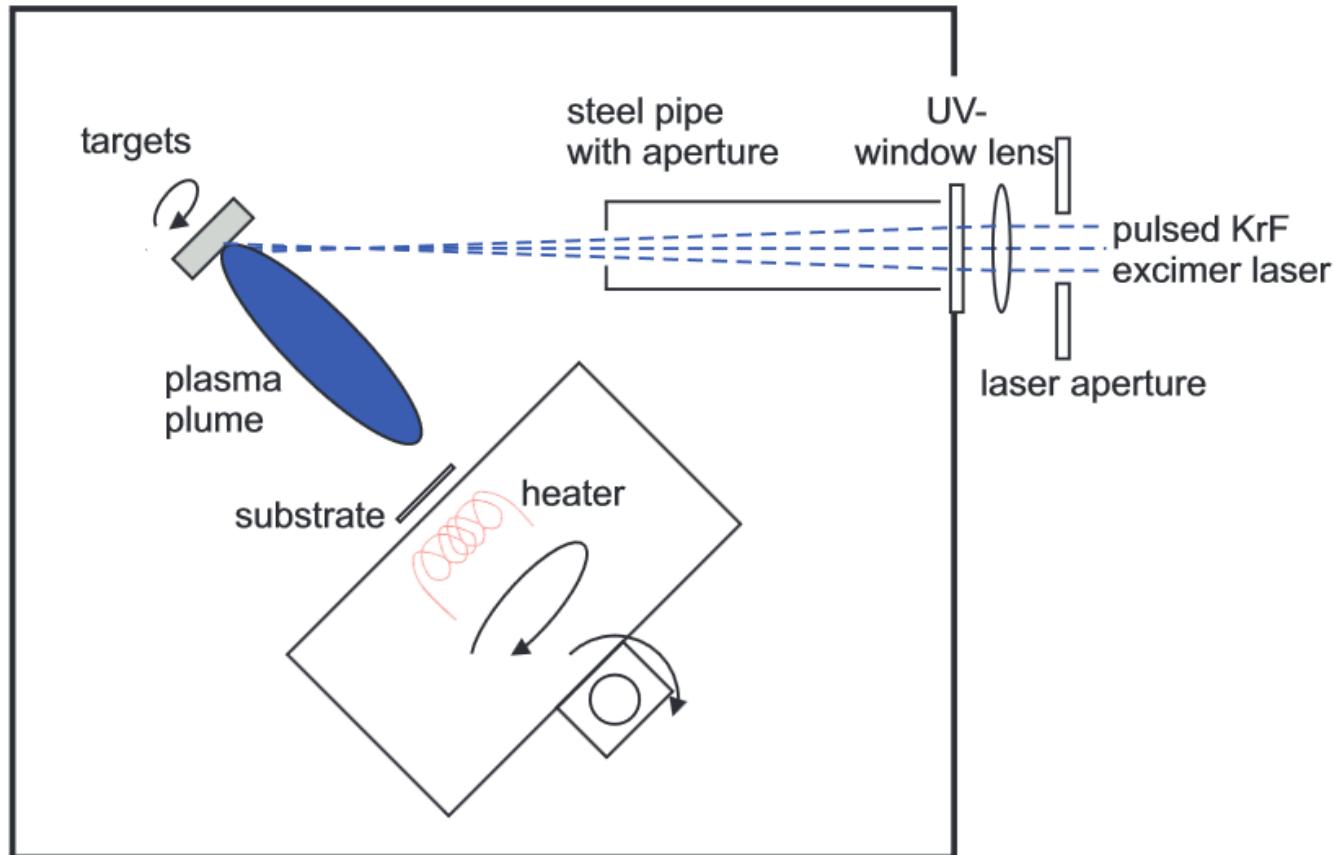
Performance of Vertically Aligned, Ordered Arrays of Silicon Nanowies with a Porous Electrode."Analytical Chemistry 83, 4724 (2011).

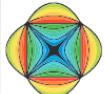
- Mixed-signal neuromorphic networks



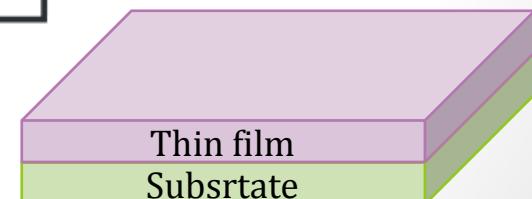
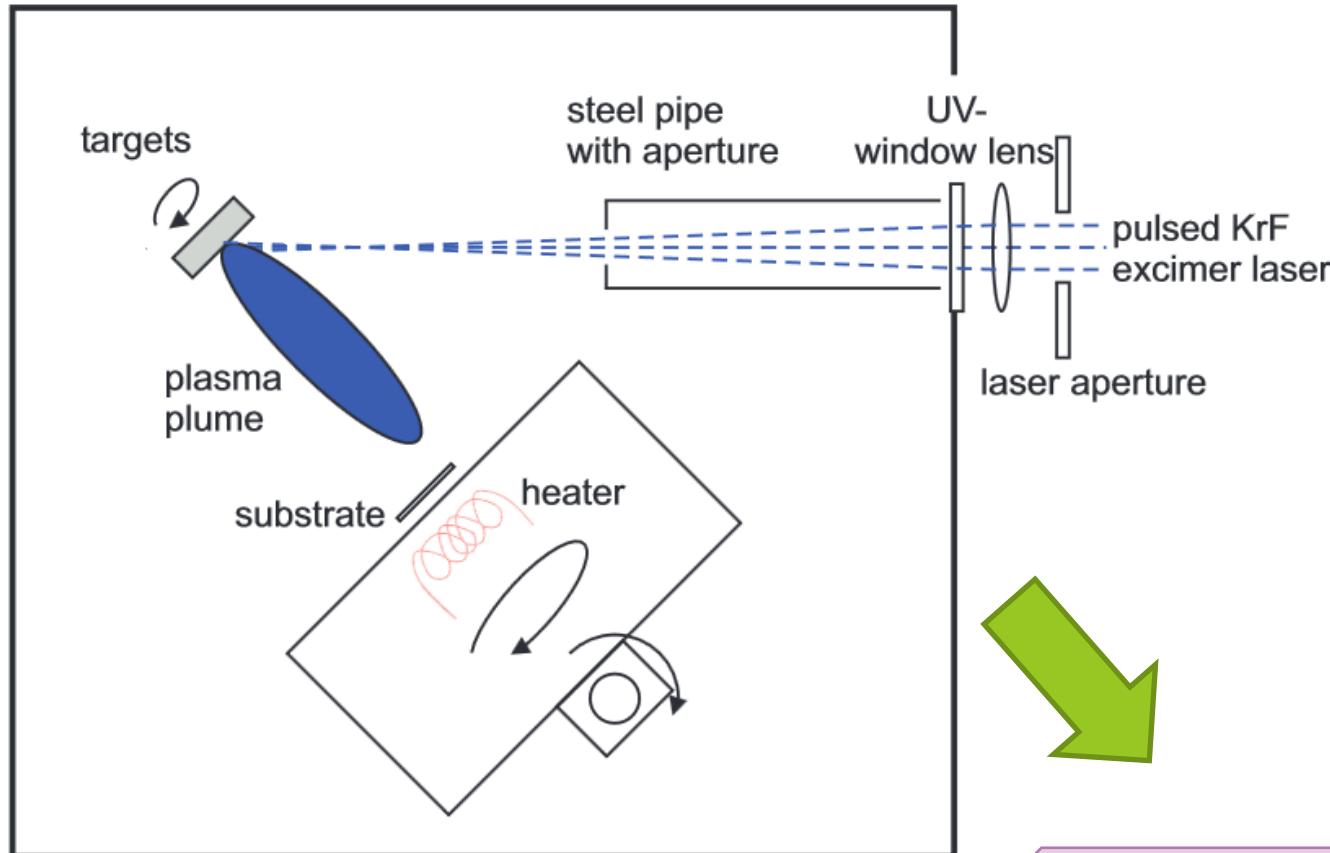


PLD for thin films





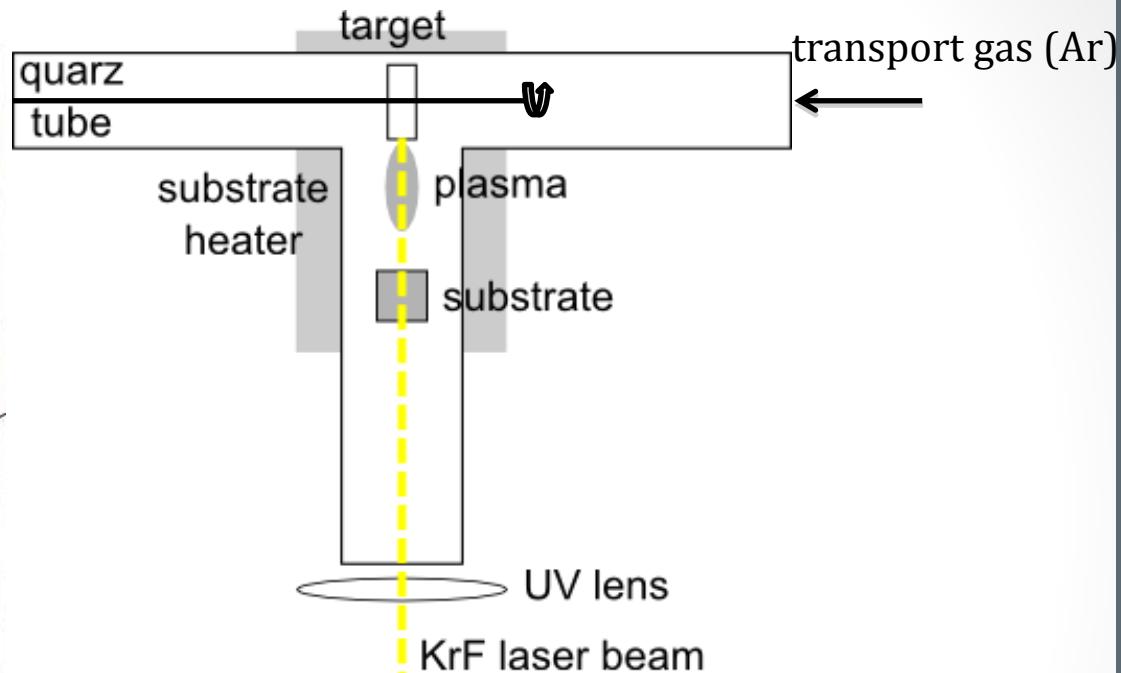
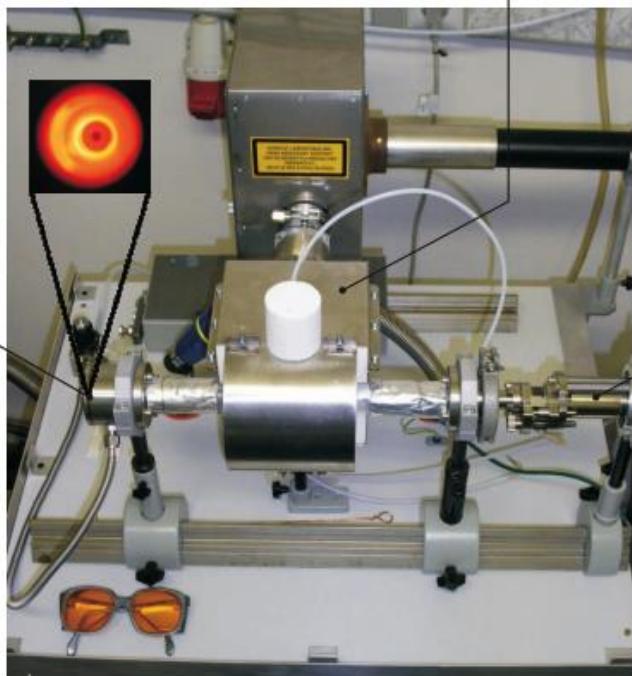
PLD for thin films



[4]



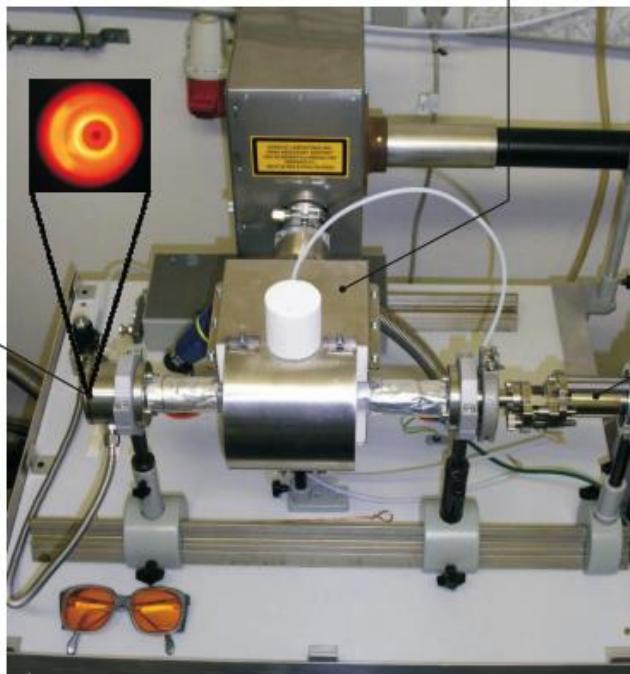
PLD for nanowires



main parameters:

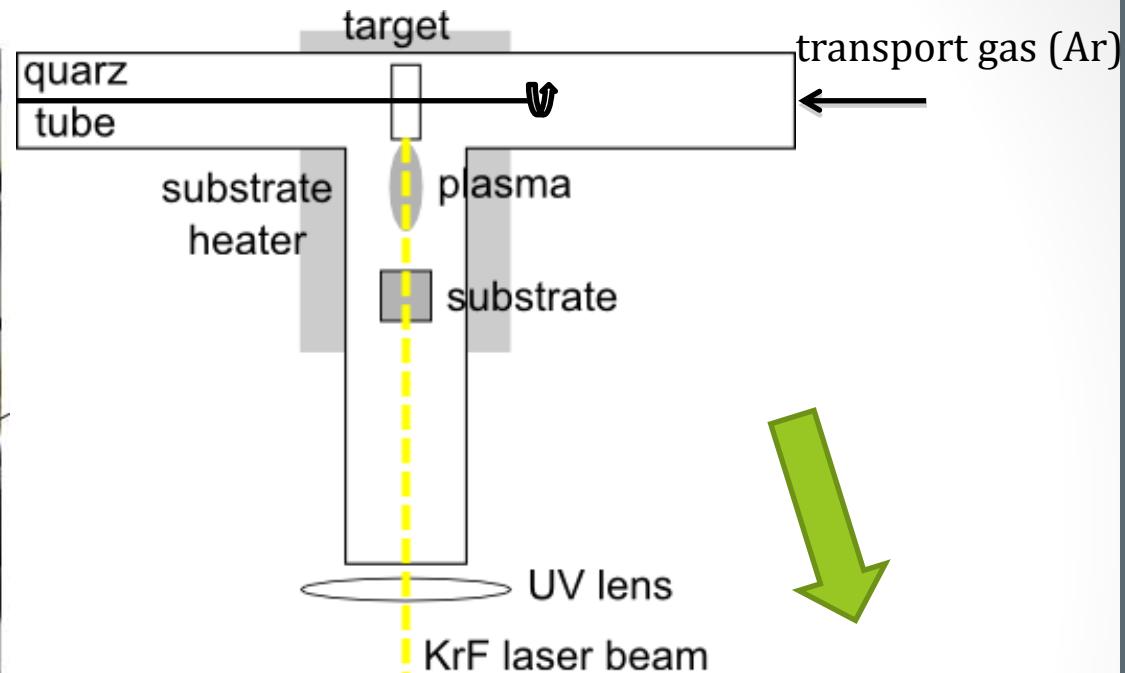
- temperature (900°C)
- pressure (100-200mbar)
- # of pulses
- composition of the transport gas (Ar, O₂, or mix)
- distance between target and substrate (1-5cm)

Andreas Rahm: Growth and Characterization of ZnO-based Nanostructures, Dissertation, University of Leipzig, 2007



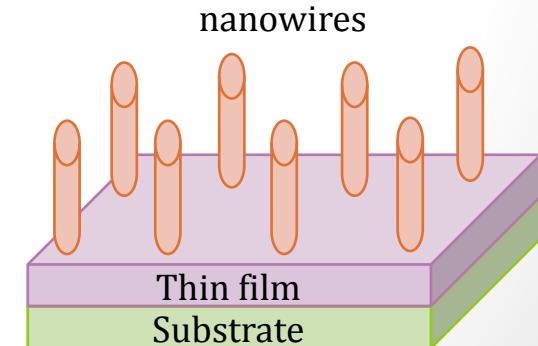
Andreas Rahm: Growth and Characterization of ZnO-based Nanostructures, Dissertation, University of Leipzig, 2007

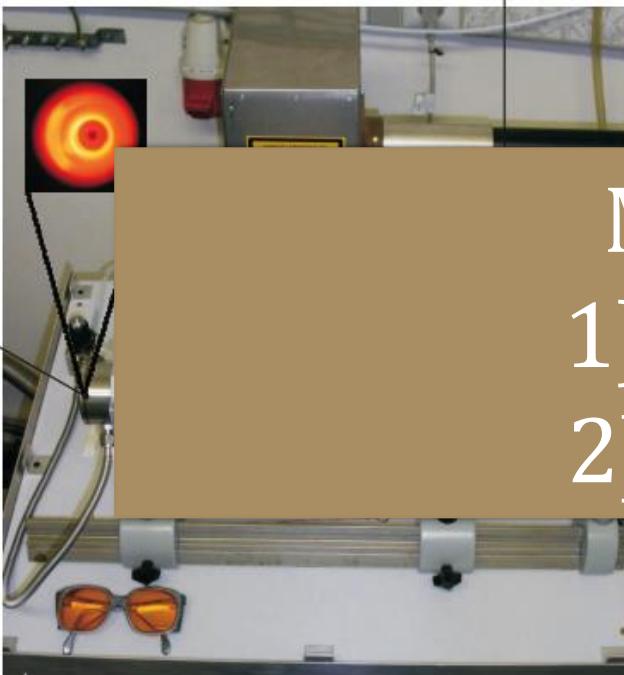
PLD for nanowires



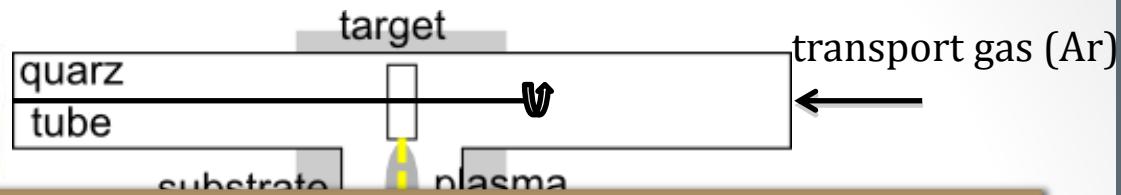
main parameters:

- temperature (900°C)
- pressure (100-200mbar)
- # of pulses
- composition of the transport gas (Ar, O₂, or mix)
- distance between target and substrate (1-5cm)





PLD for nanowires



Modifications:

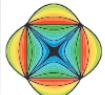
- 1) High pressure
- 2) Transport gas



main parameters:

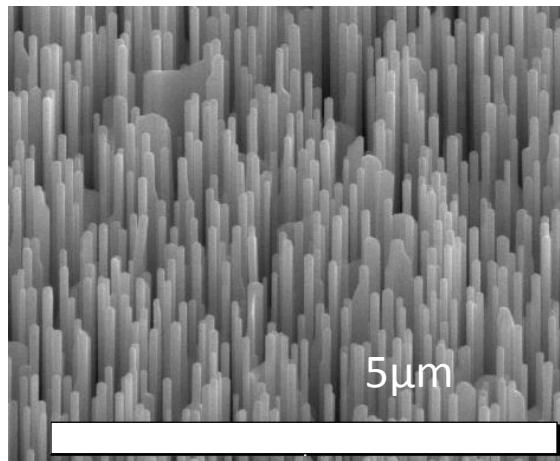
- temperature (900°C)
- pressure (100-200mbar)
- # of pulses
- composition of the transport gas (Ar, O₂, or mix)
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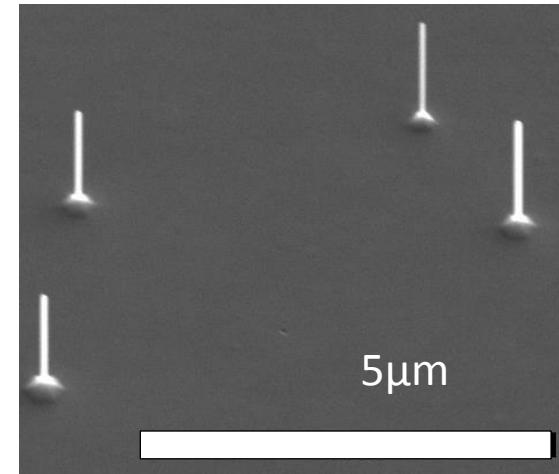


Nanowires grown by PLD

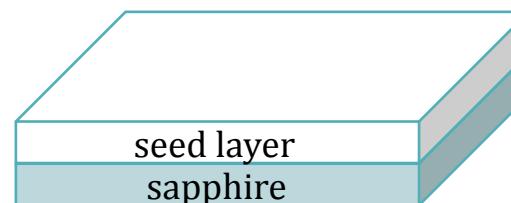
$T \approx 900^\circ\text{C}$



ZnO nanowires on
pure a-plane sapphire

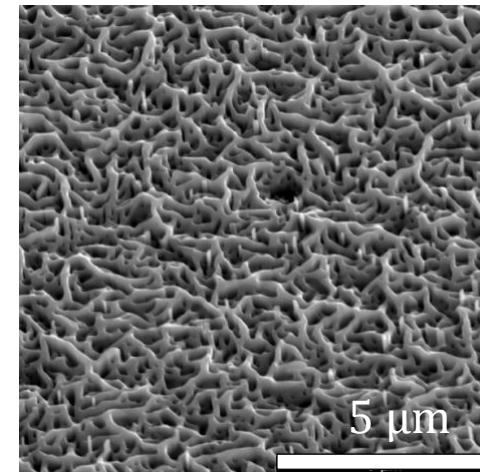
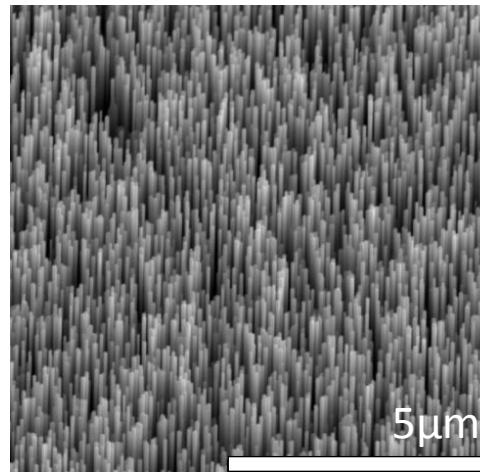
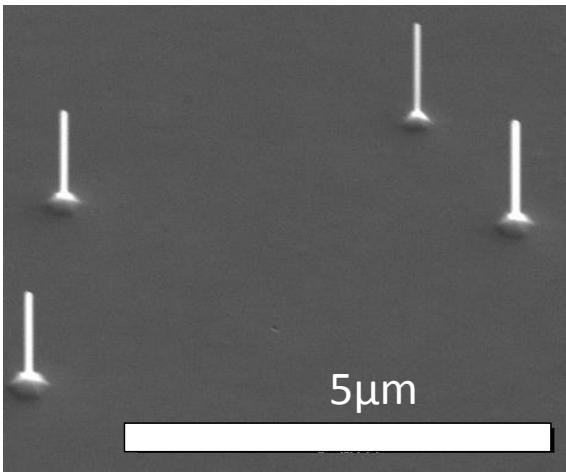


ZnO nanowires on
a-plane sapphire with
200 nm ZnO seed layer



Andreas Rahm: Growth and
Characterization of ZnO-based
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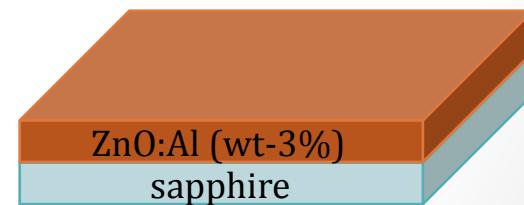
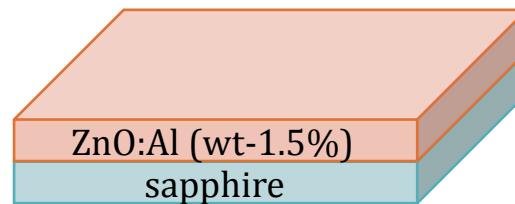
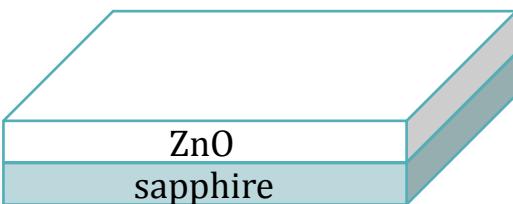
Nanowires on ZnO:Al

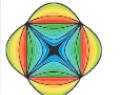
 $T \approx 900^\circ\text{C}$ 

pure ZnO

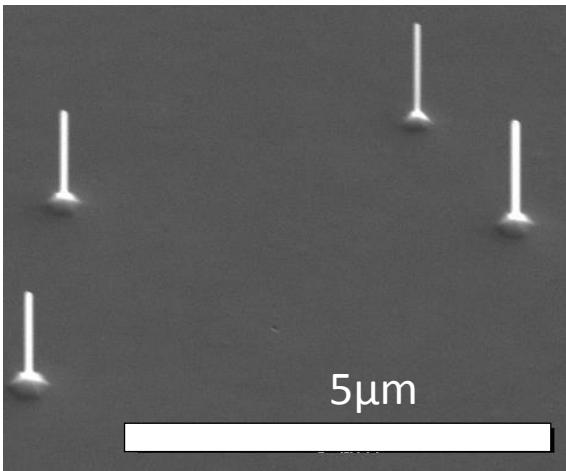
ZnO+1.5%Al

ZnO+3%Al

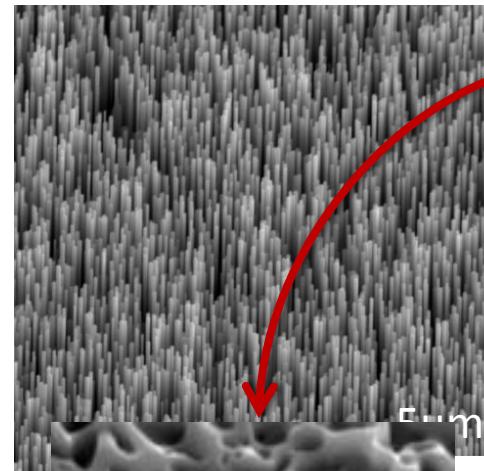
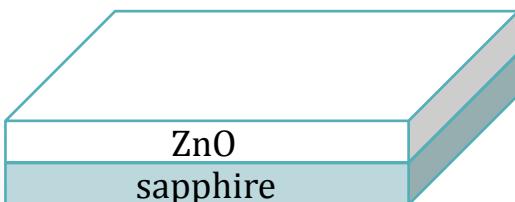




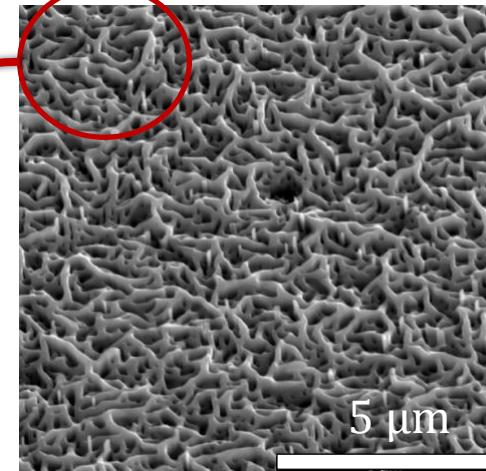
Nanowires on ZnO:Al

 $T \approx 900^\circ\text{C}$ 

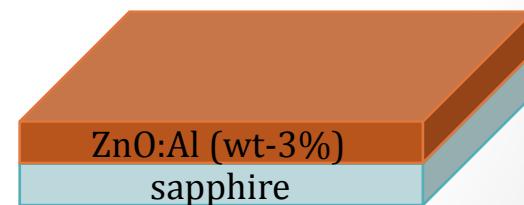
pure ZnO



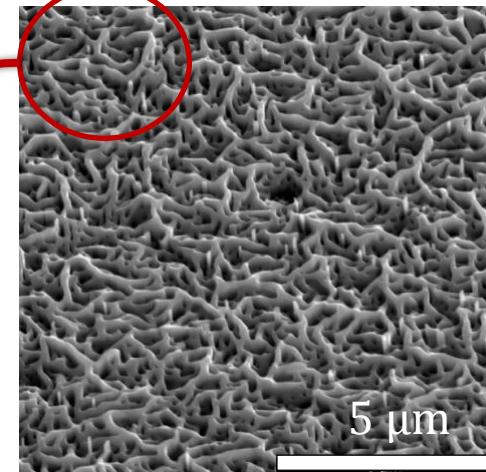
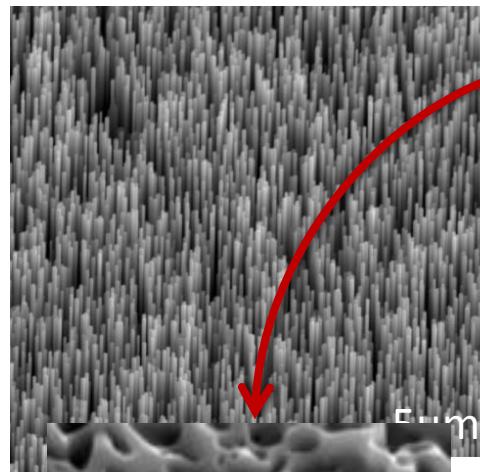
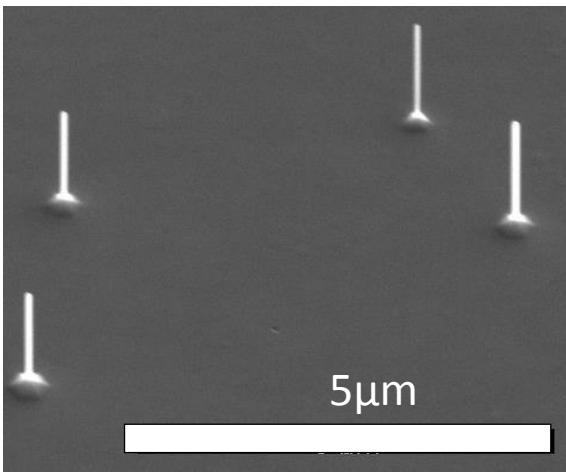
sapphire



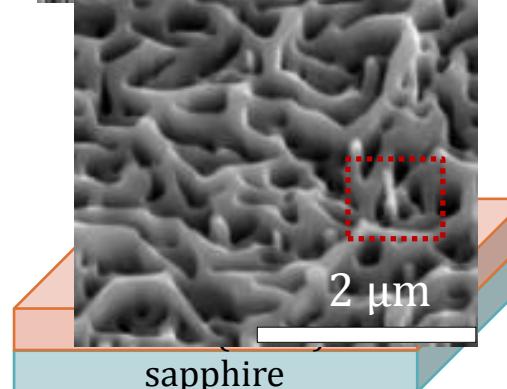
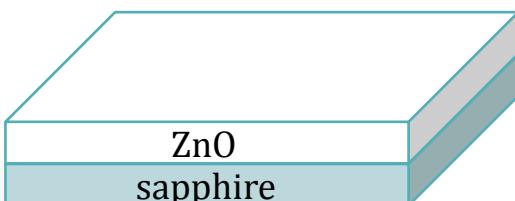
ZnO+3%Al



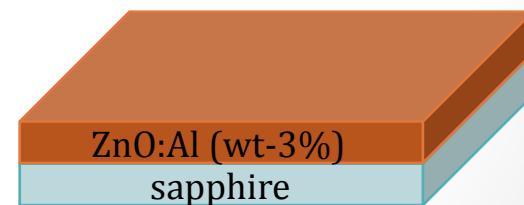
Nanowires on ZnO:Al

 $T \approx 900^\circ\text{C}$ 

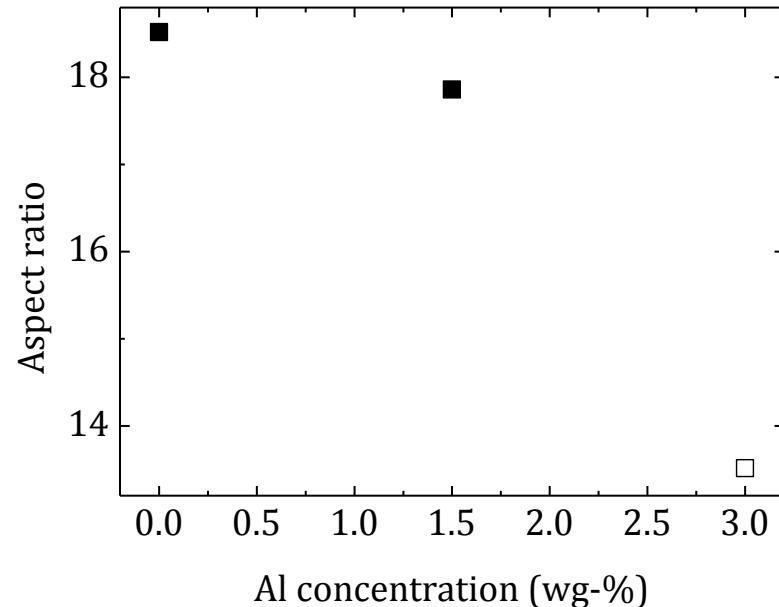
pure ZnO



ZnO+3%Al

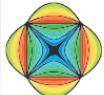


Nanowires on ZnO:Al

 $T_c=900^\circ\text{C}$ 

pure ZnO

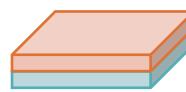




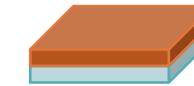
Surface morphology: AFM



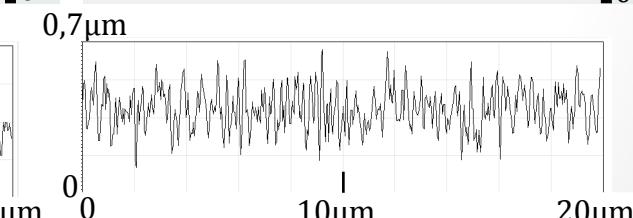
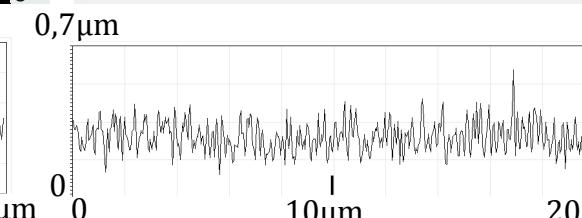
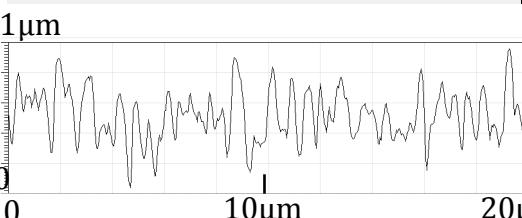
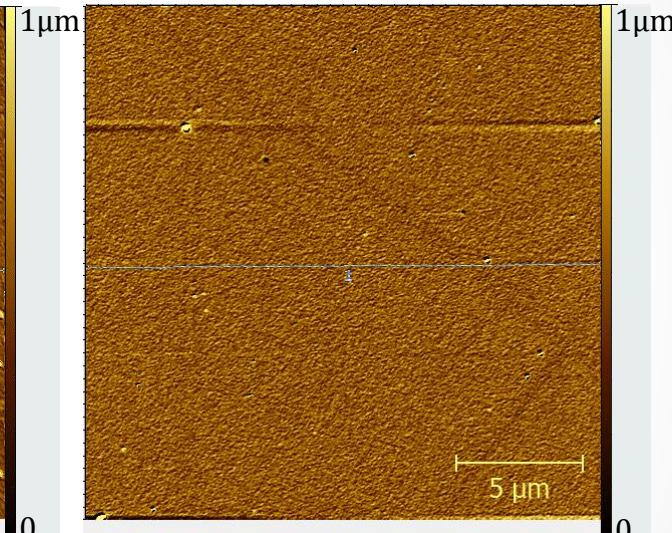
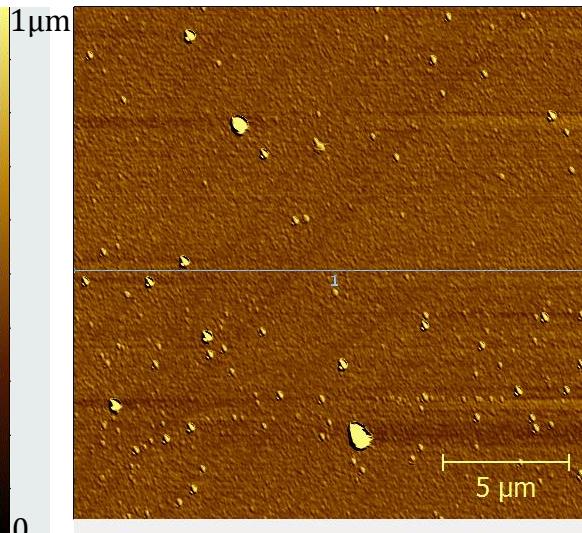
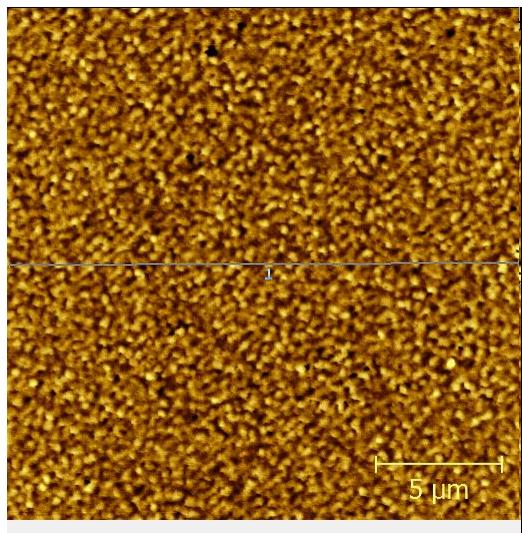
pure ZnO

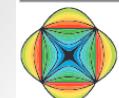


ZnO+1.5%Al

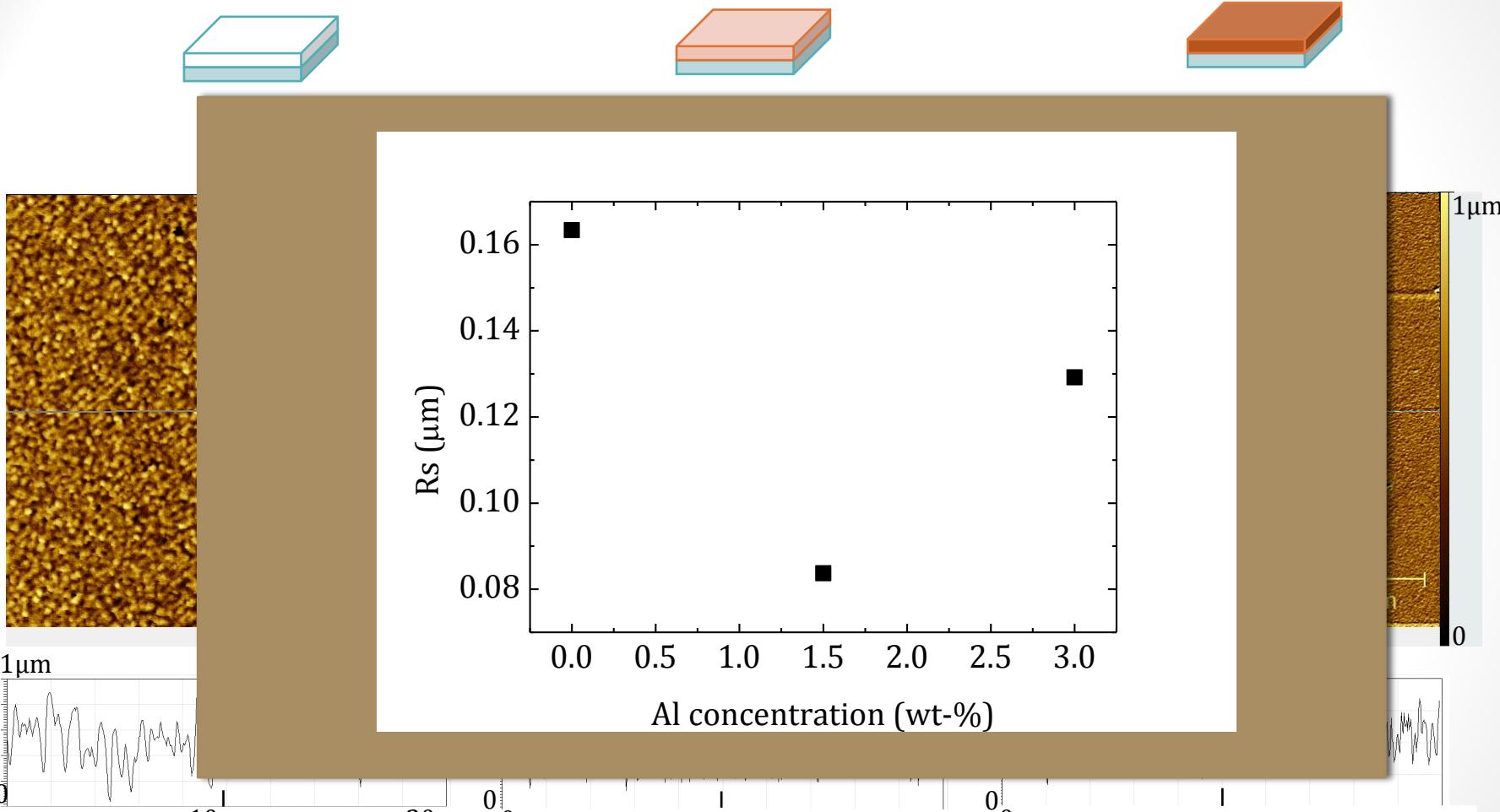


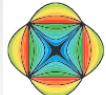
ZnO+3%Al





Surface morphology: AFM





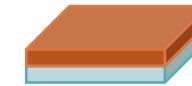
XRD wide 2θ-scan



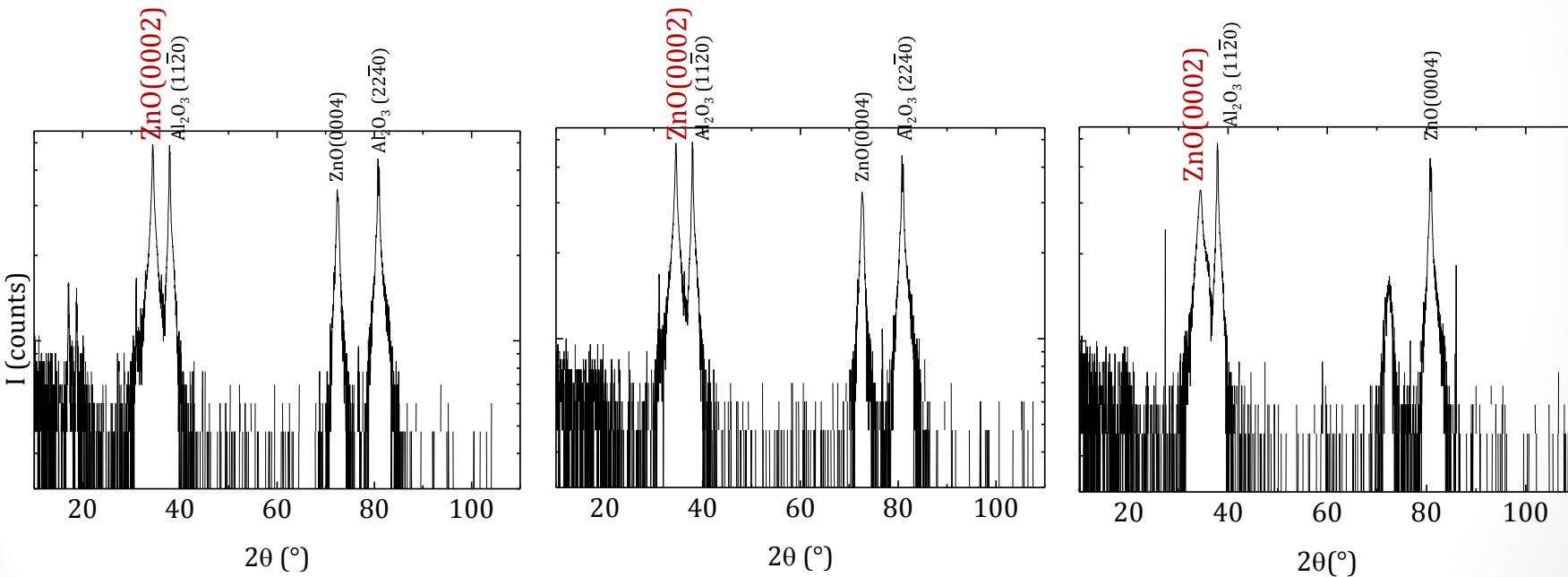
pure ZnO

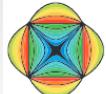


ZnO+1.5%Al



ZnO+3%Al

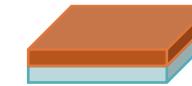


XRD Ω -scan

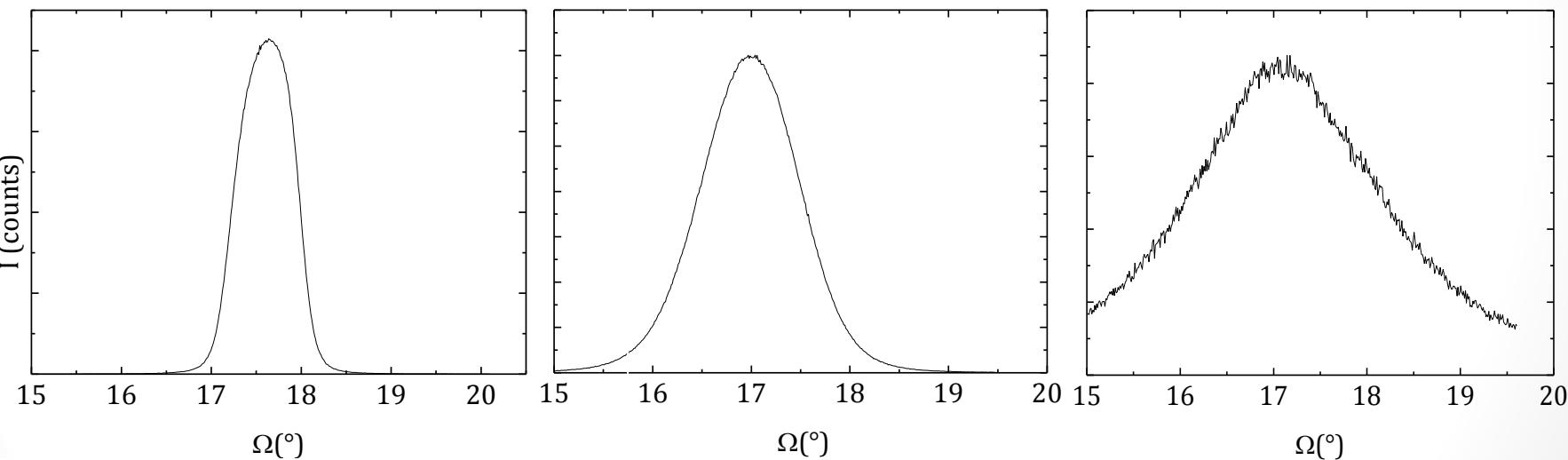
pure ZnO

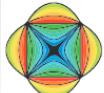
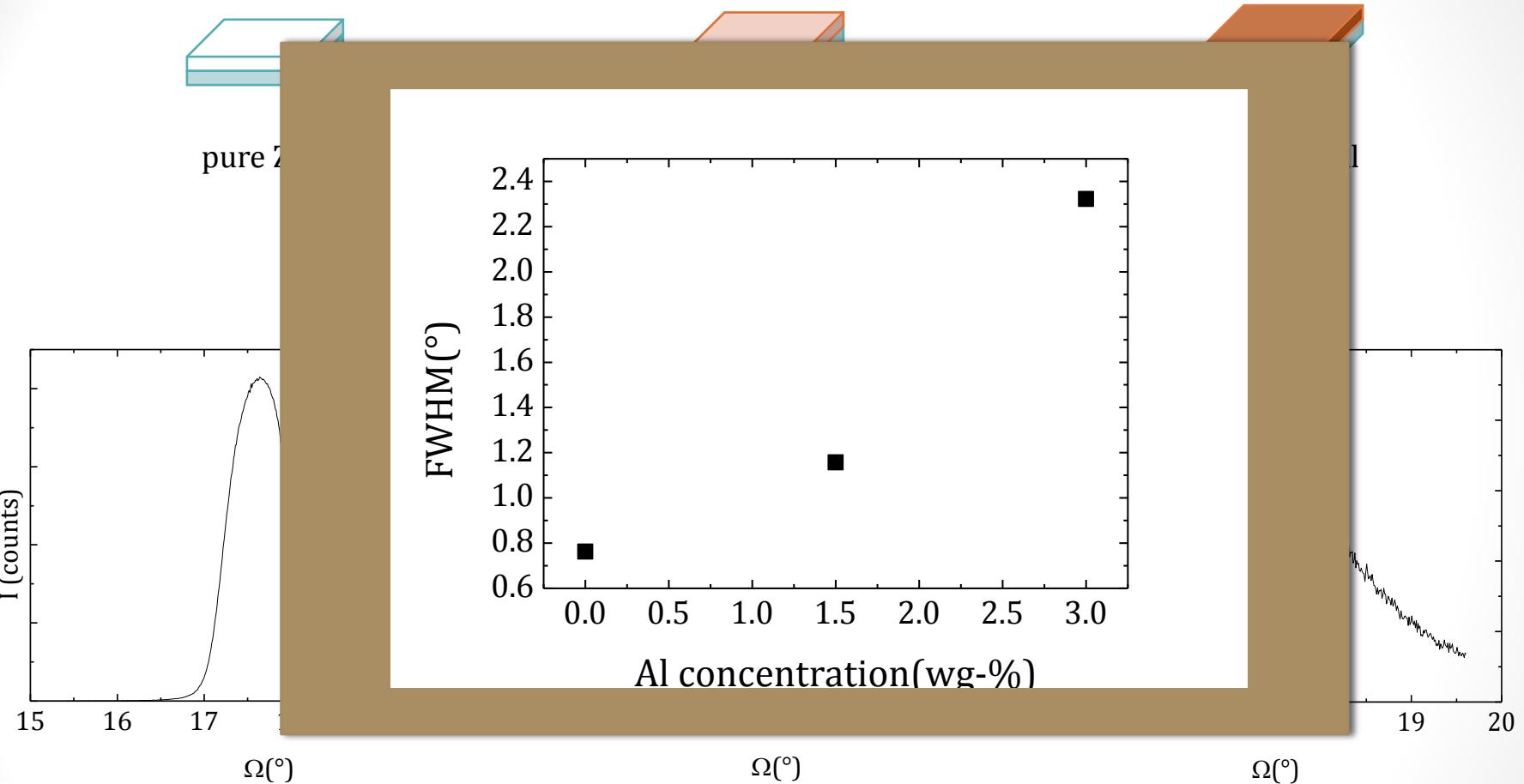


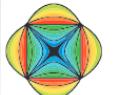
ZnO+1.5%Al



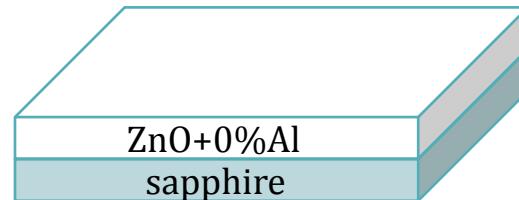
ZnO+3%Al



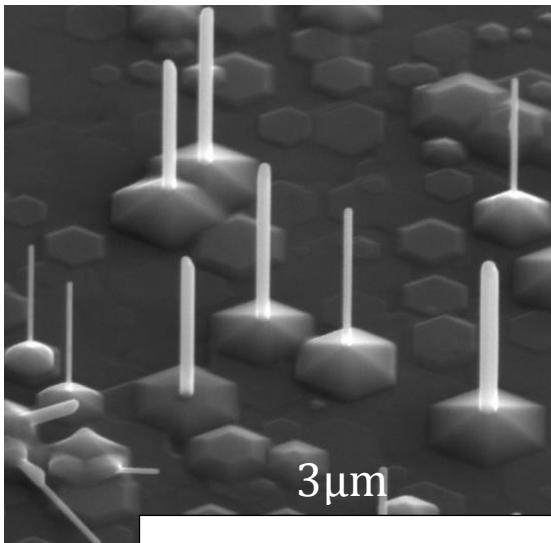
XRD Ω -scan



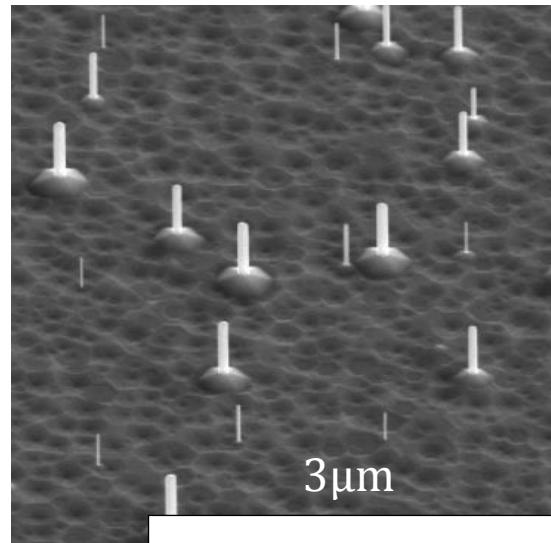
Reduction of the growth temperature



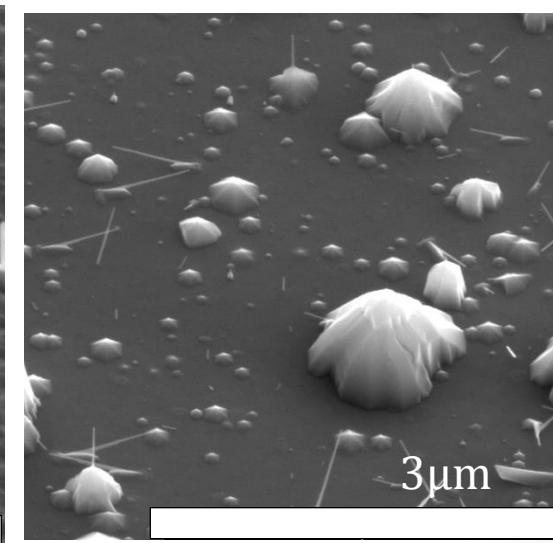
$T \approx 900^\circ\text{C}$

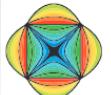


$T \approx 700^\circ\text{C}$

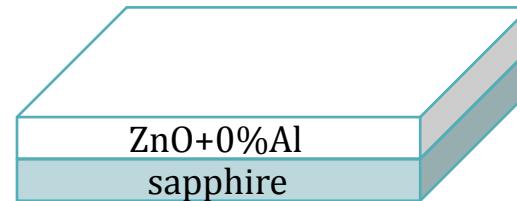
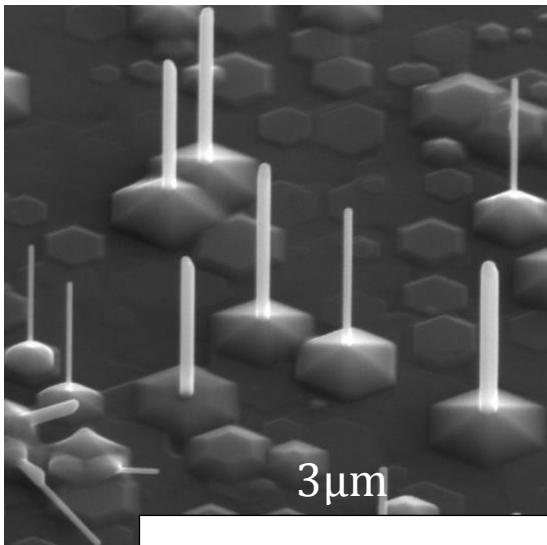
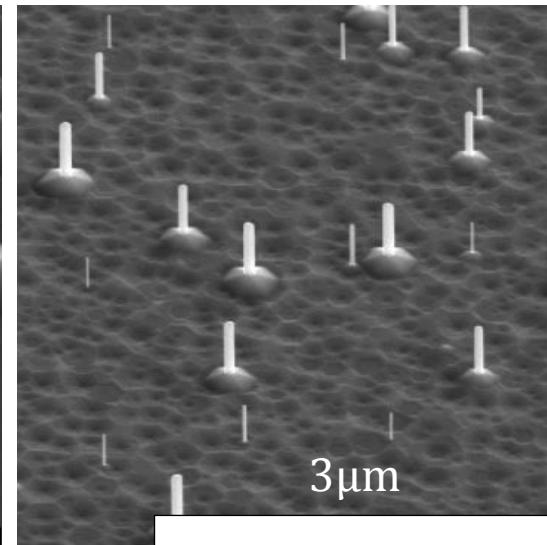
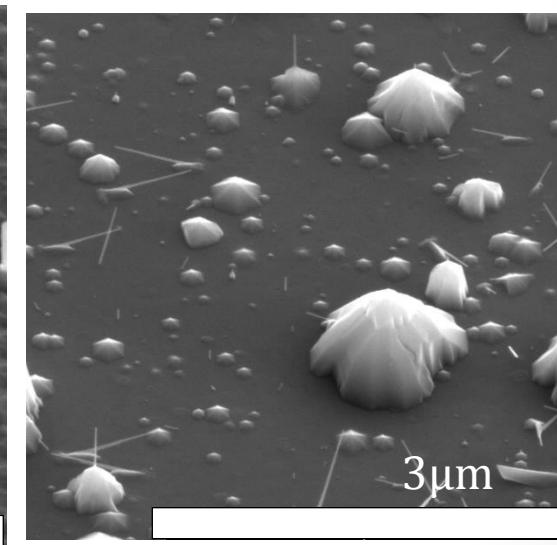


$T \approx 400^\circ\text{C}$

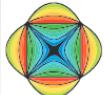




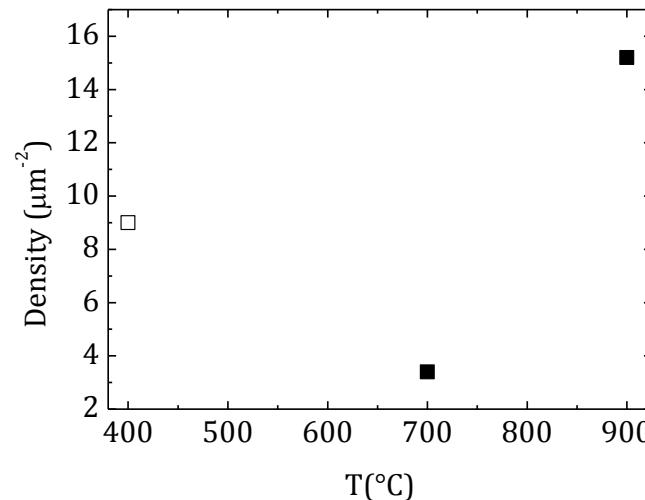
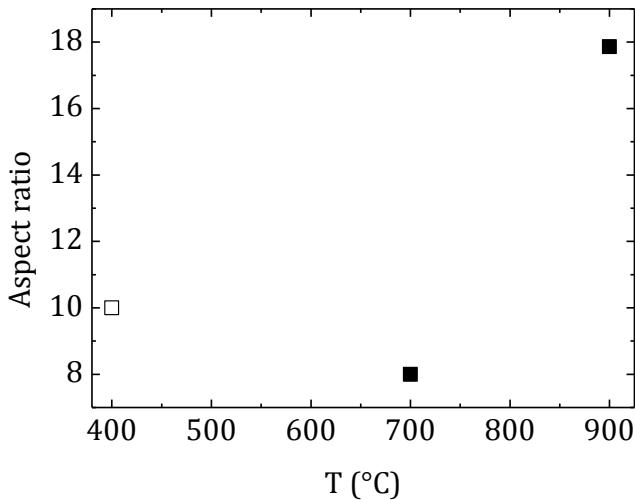
Reduction of the growth temperature

 $T \approx 900^\circ\text{C}$  $T \approx 700^\circ\text{C}$  $T \approx 400^\circ\text{C}$ **AGGLOMERATIONS**

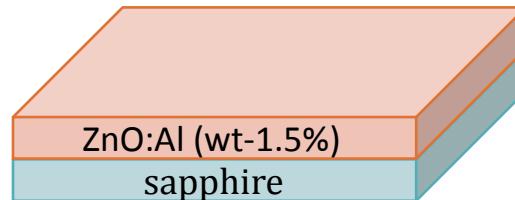
(10)



Reduction of the growth temperature



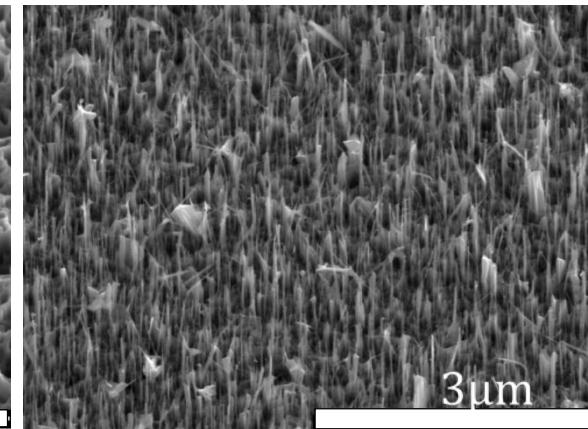
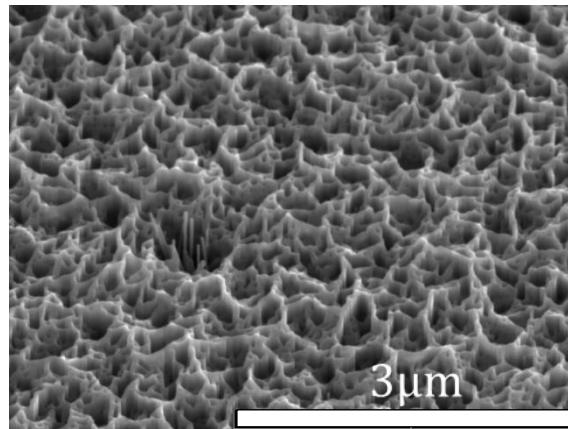
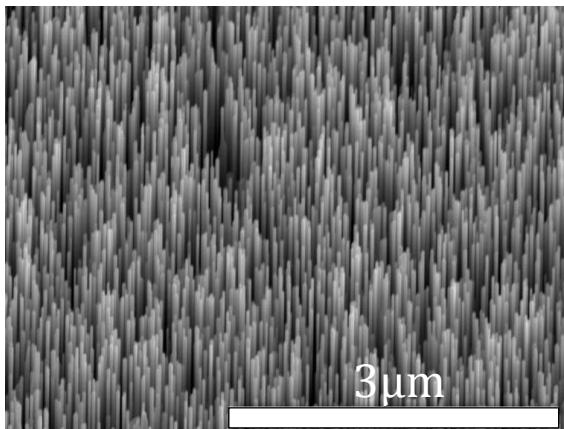
Reduction of the growth temperature

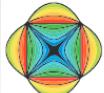


$T \approx 900^\circ\text{C}$

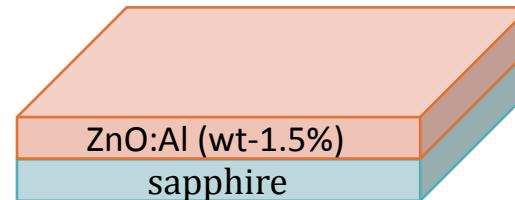
$T \approx 700^\circ\text{C}$

$T \approx 400^\circ\text{C}$





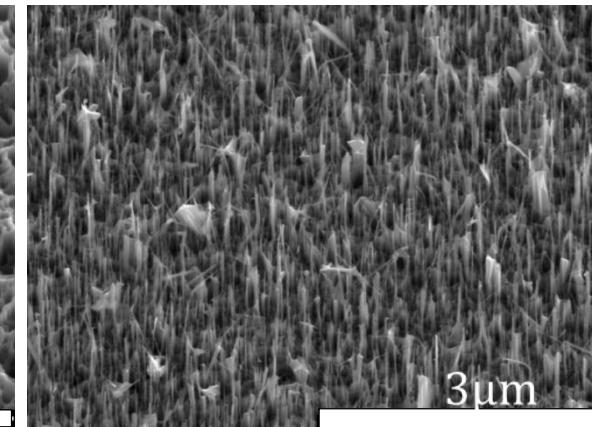
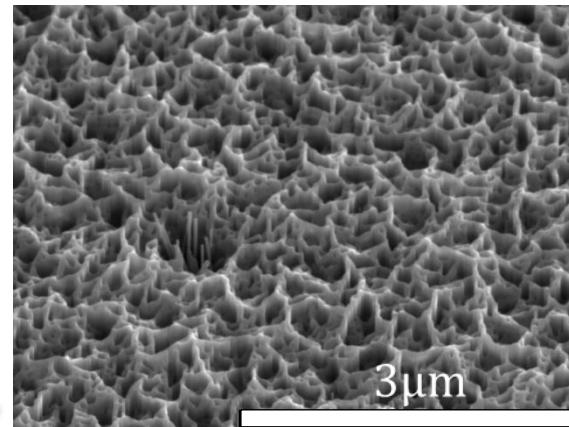
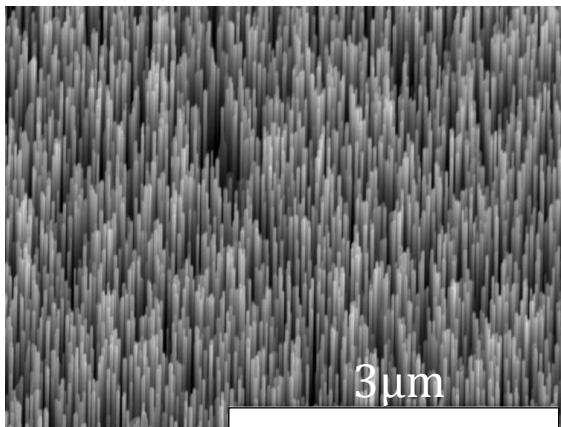
Reduction of the growth temperature



$T \approx 900^\circ\text{C}$

$T \approx 700^\circ\text{C}$

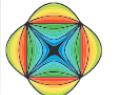
$T \approx 400^\circ\text{C}$



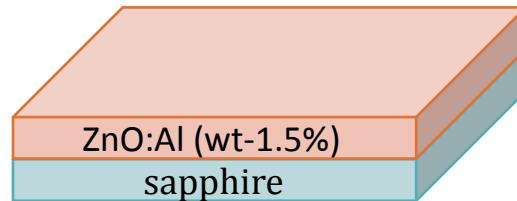
AGGLOMERATIONS



[11]



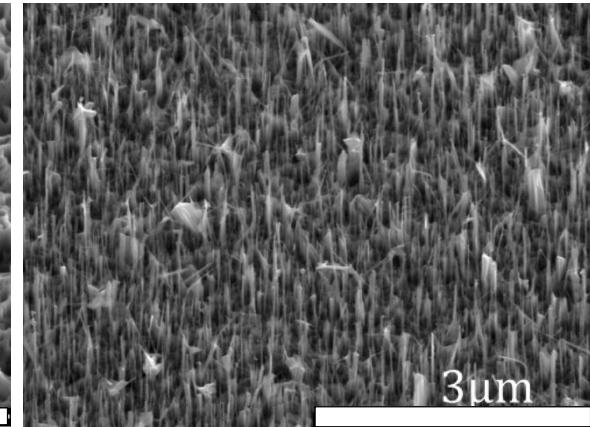
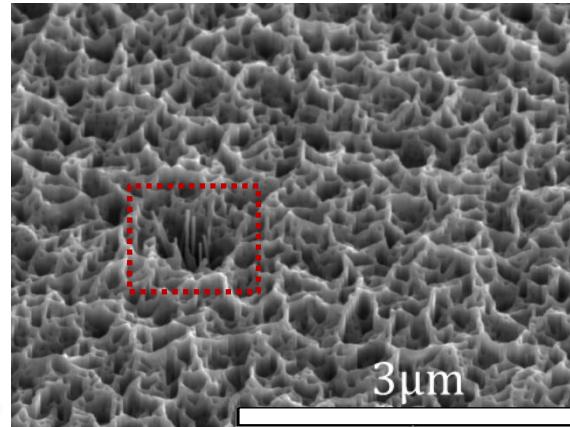
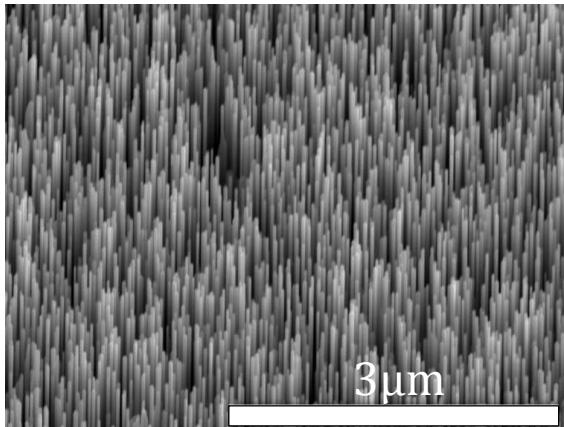
Reduction of the growth temperature

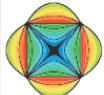


$T \approx 900^\circ\text{C}$

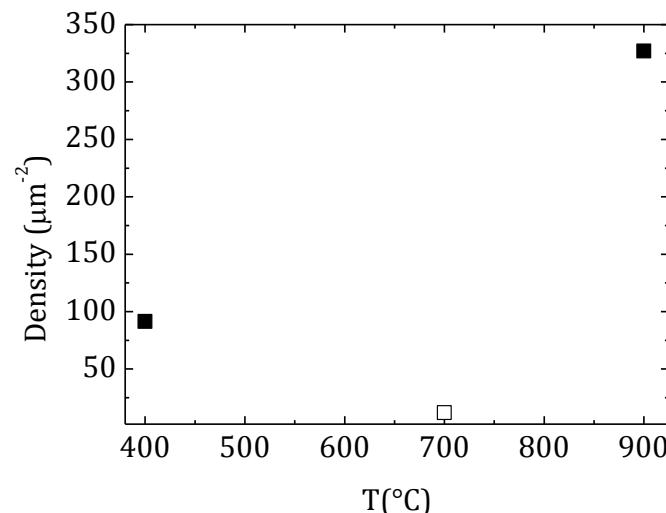
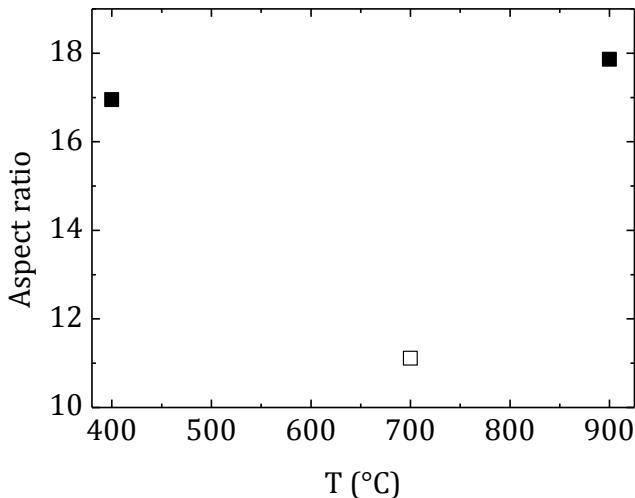
$T \approx 700^\circ\text{C}$

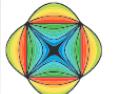
$T \approx 400^\circ\text{C}$



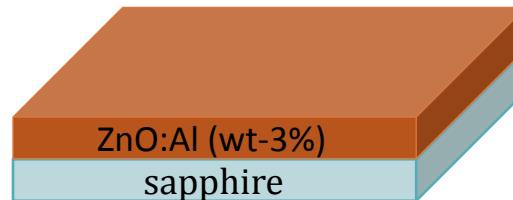


Reduction of the growth temperature





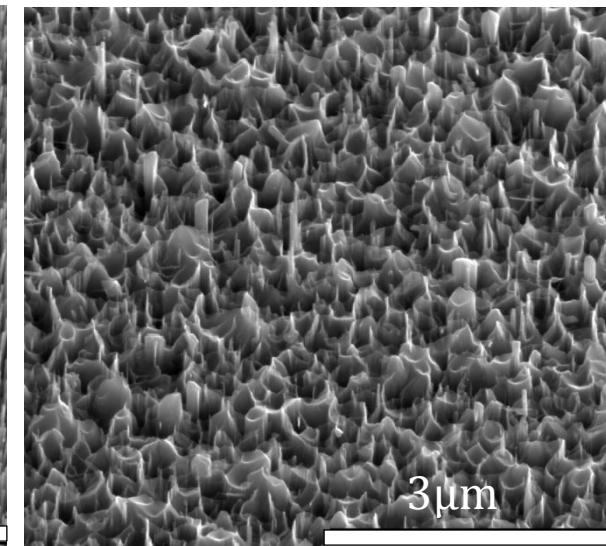
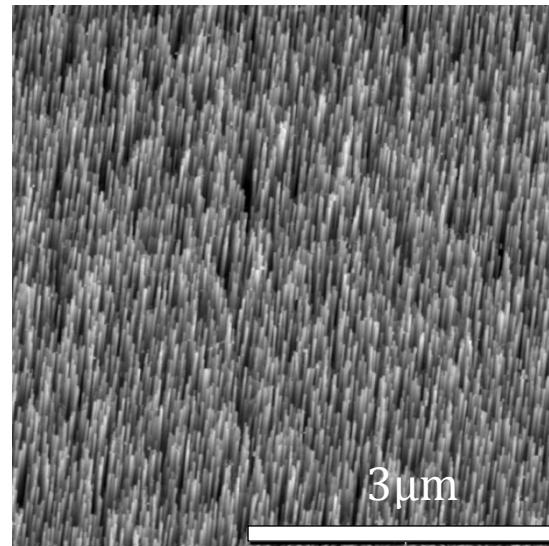
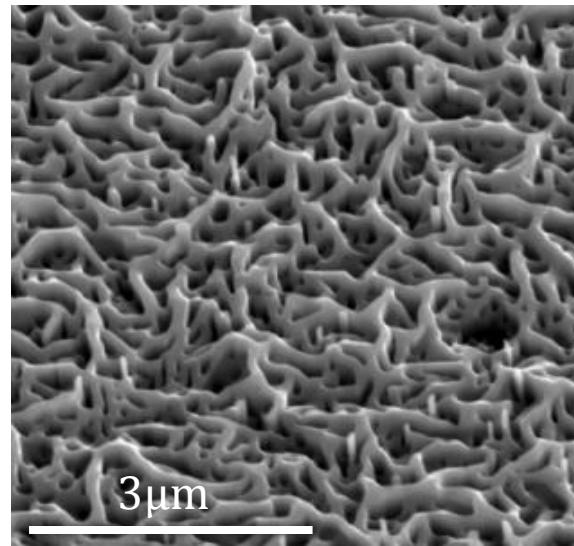
Reduction of the growth temperature



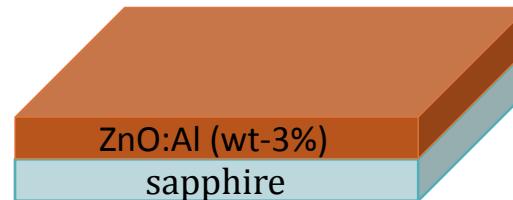
$T \approx 900^\circ\text{C}$

$T \approx 700^\circ\text{C}$

$T \approx 400^\circ\text{C}$



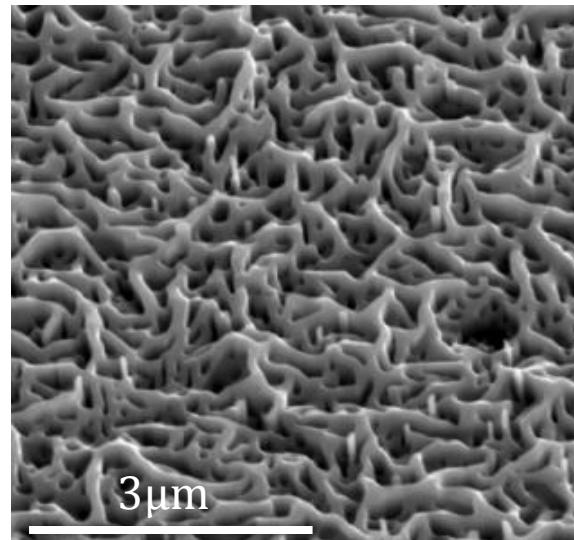
Reduction of the growth temperature



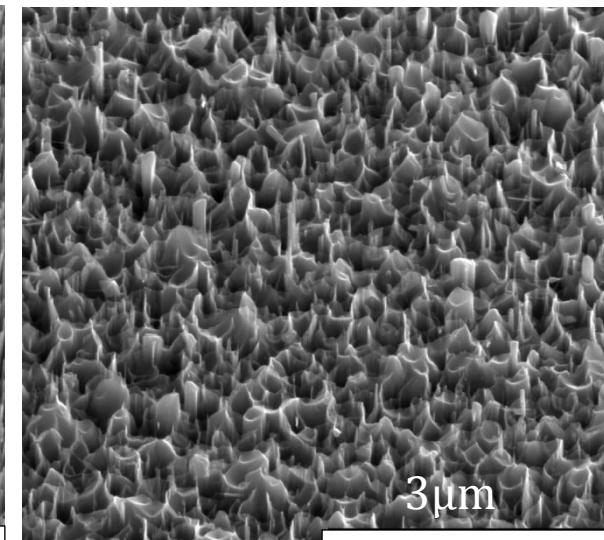
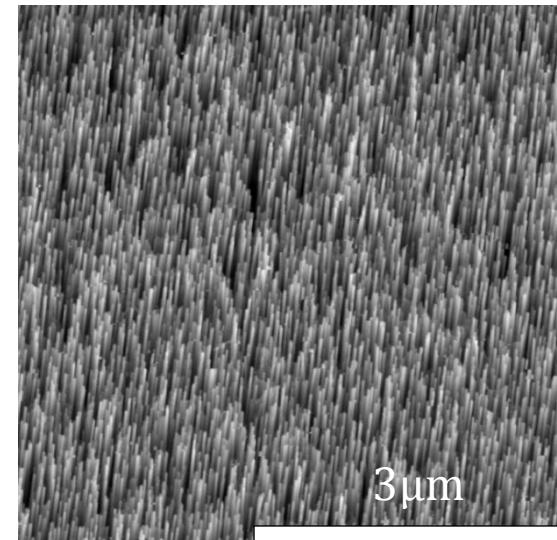
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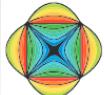
$T \approx 700^\circ\text{C}$

$T \approx 400^\circ\text{C}$

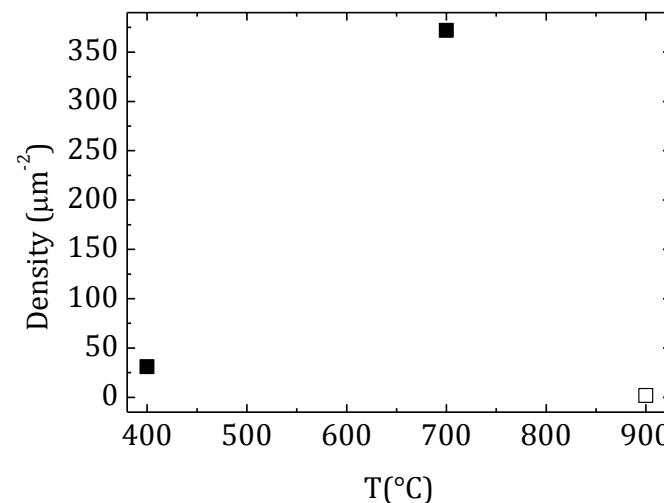
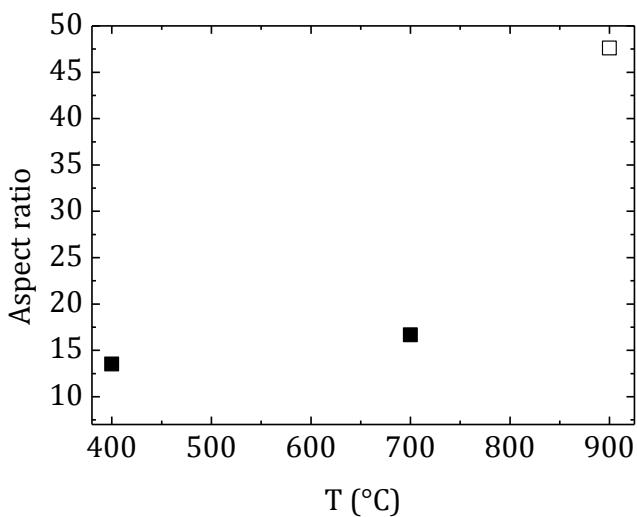


AGGLOMERATIONS

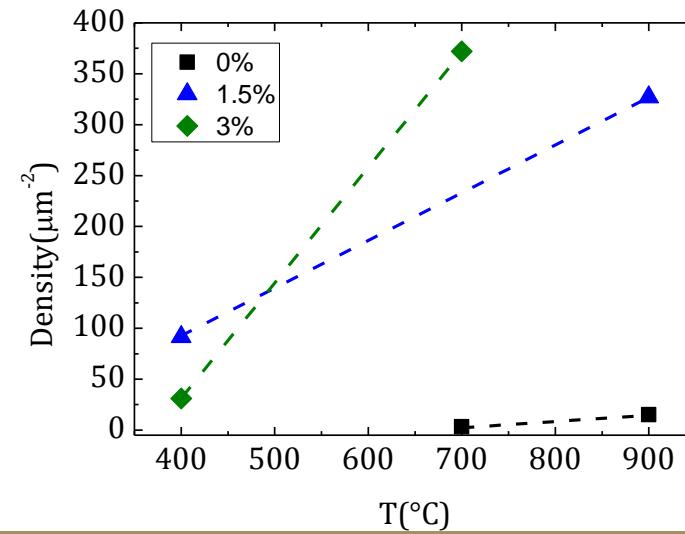
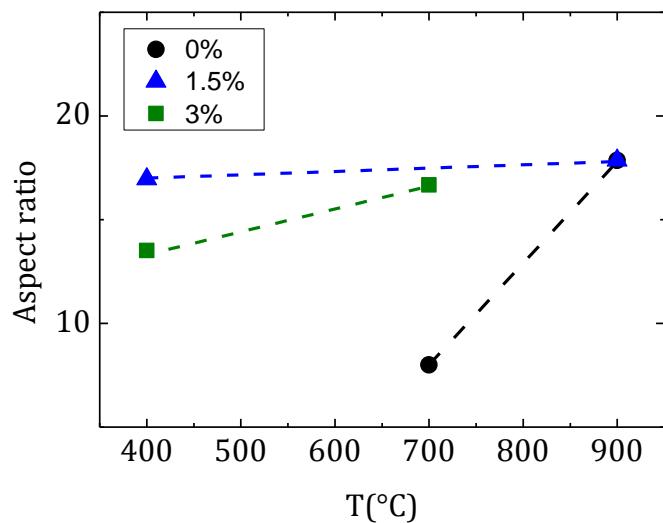




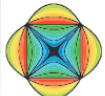
Reduction of the growth temperature



Temperature dependence



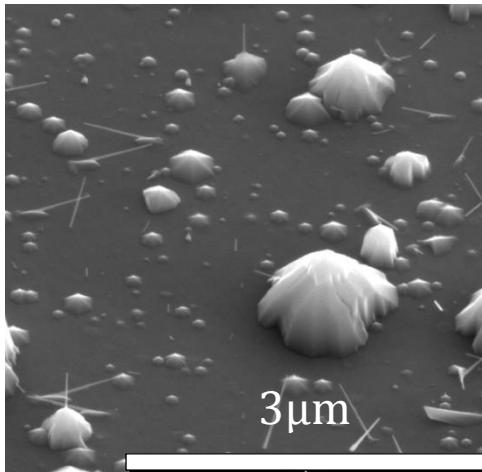
Agglomerations

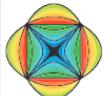


Agglomerations



Particles

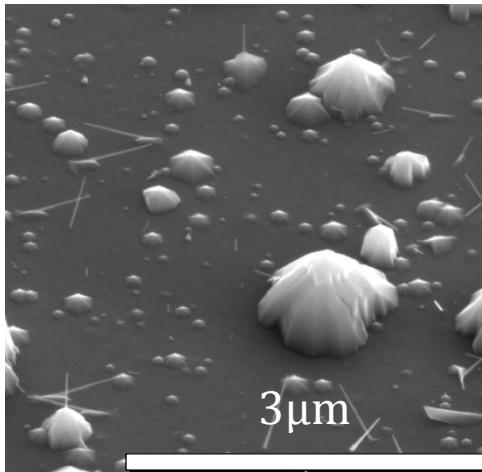




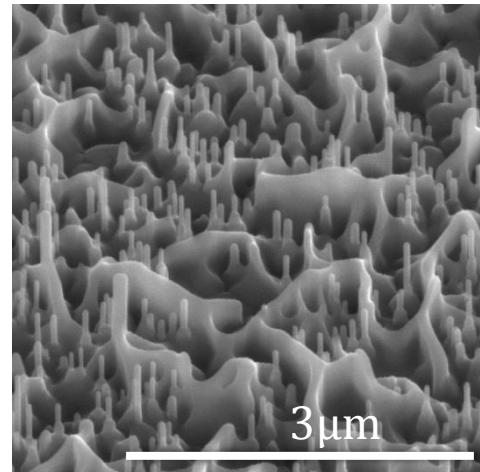
Agglomerations

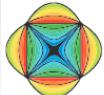


Particles



Walls

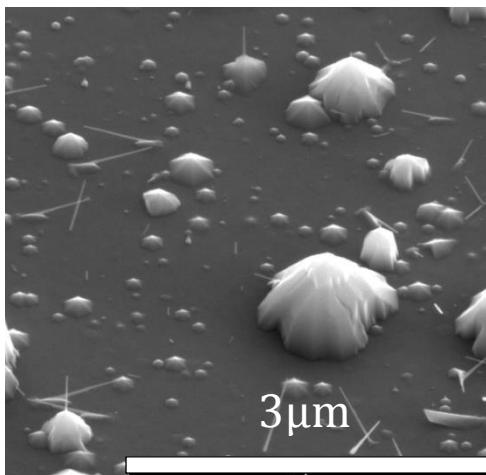




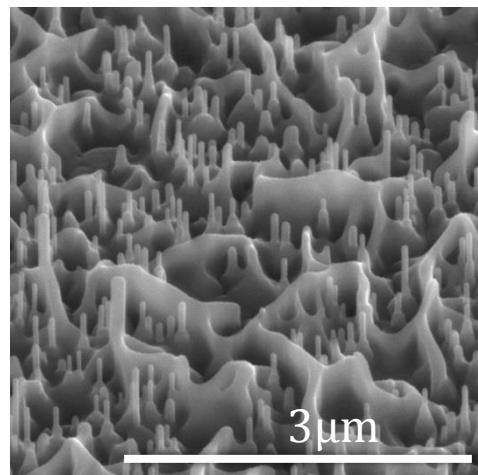
Agglomerations



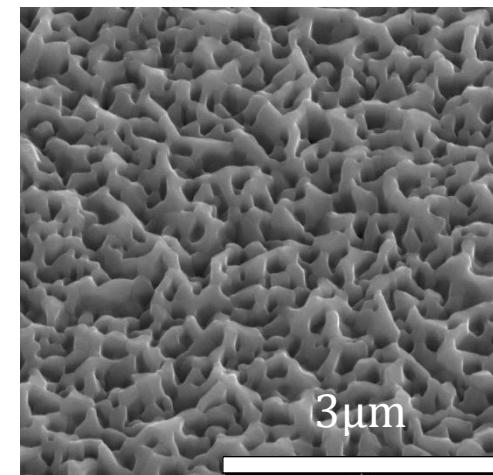
Particles

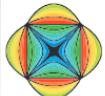


Walls



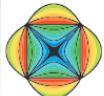
Honeycombs





Summary

- Content of Al in the ZnO nucleation film has an influence on the growth process



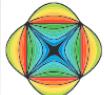
Summary

- Content of Al in the ZnO nucleation film has an influence on the growth process
- Growth temperature for NW can be reduced down to 400°C



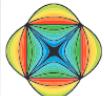
Summary

- Content of Al in the ZnO nucleation film has an influence on the growth process
- Growth temperature for NW can be reduced down to 400°C
- $T \downarrow = \{ \begin{matrix} \text{aspect ratio } \downarrow \\ \dots \end{matrix}$



Summary

- Content of Al in the ZnO nucleation film has an influence on the growth process
- Growth temperature for NW can be reduced down to 400°C
- $T \downarrow = \begin{cases} \text{aspect ratio } \downarrow \\ \text{agglomerations } \uparrow \end{cases}$



Thanks to:

- Dipl.-Ing. H. Hochmuth
- Dipl.-Phys. J. Lenzner
- G. Ramm
- Semiconductor Physics Group



Thank you for attention!