Gas phase epitaxy
Example: AlGaInN growth by MOVPE

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Examples of questions

How does pressure in the reactor influence the growth rate of AlGaAs?

How does total flow influence the Mg incorporation into AlGaN?

How does temperature influence formation of vacancies in InGaN?

How do growth breaks between InGaAs and GaAs influence the homogeneity of the quantum wells?

Examples of questions

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How

pressure
temperature
NH3 flow
TEGa flow
TMIn flow
H2 flow
N2 flow
Growth breaks
etc

influence the InGaN QW properties?

Properties: chemical composition, thickness, defect concentration, optical and electrical properties. etc

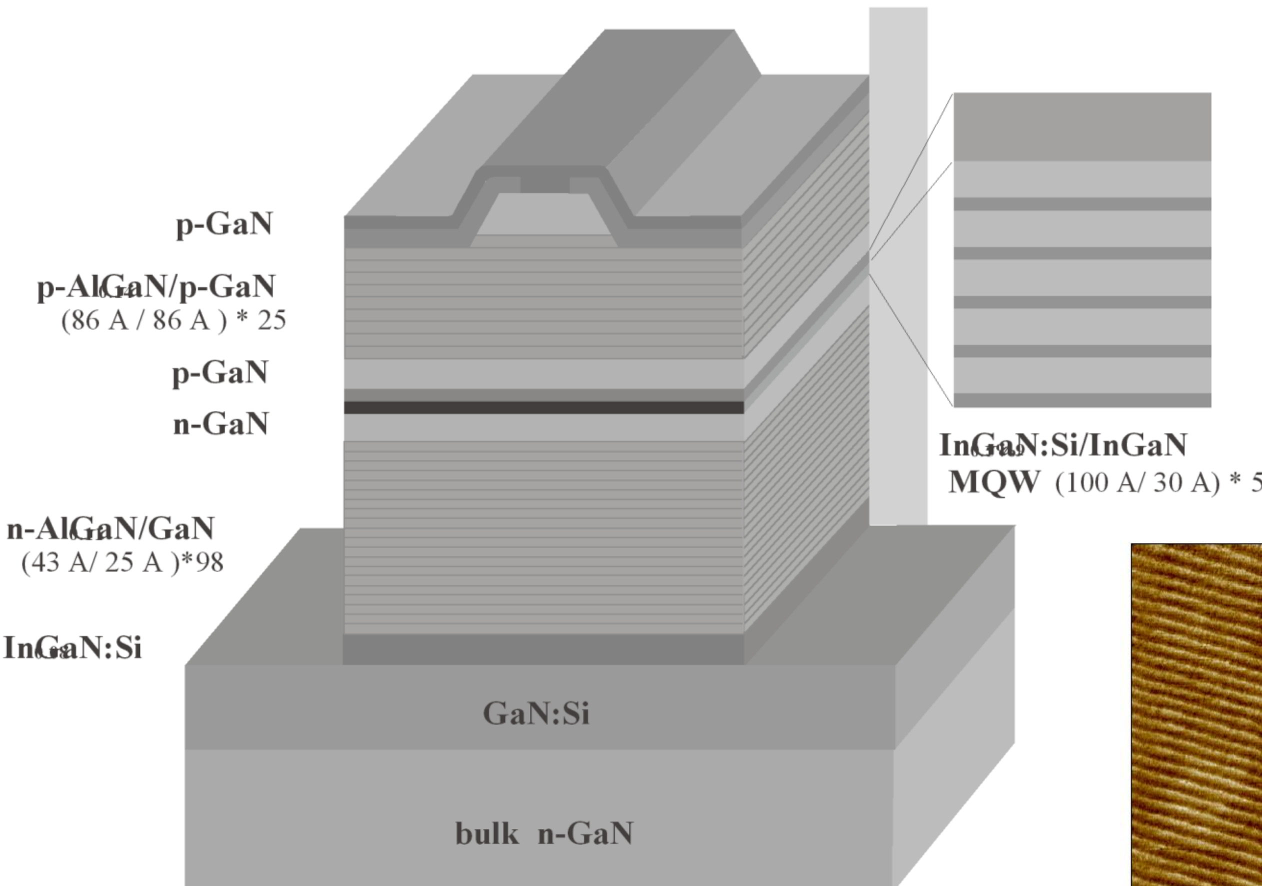
Growth parameters in MOVPE are not independent to each other.

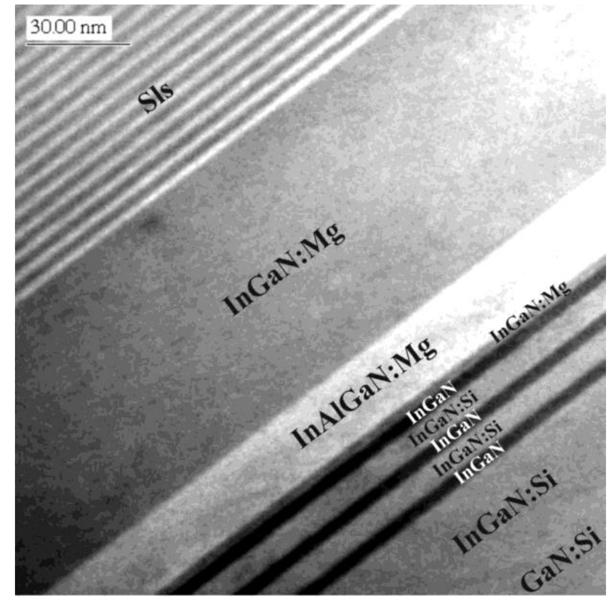
If we wished to test all combinations for only 4 values, we would have to do 4 exp10 experiments= 1 000 000

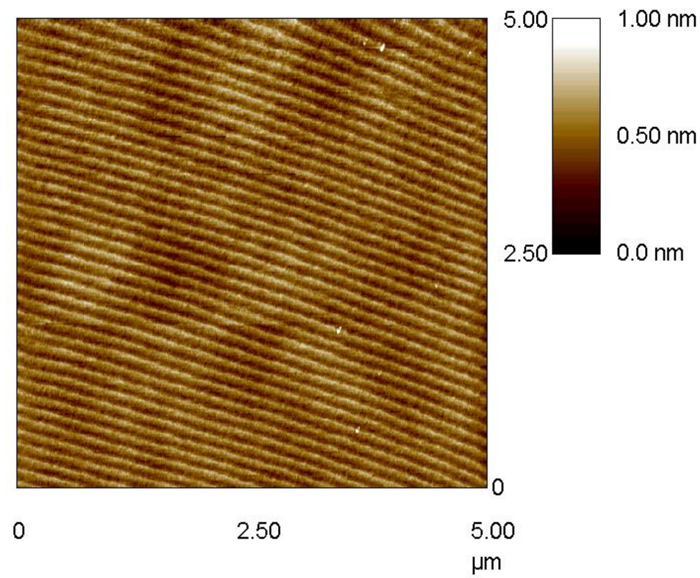
Outline

1. Effectivness of atom incorporation into GaN, AlGaN, InGaN
2. Example of influence of hydrogen on InGaN growth
3. Examples of how properties of the epi layers can be modified by growth of other layers.

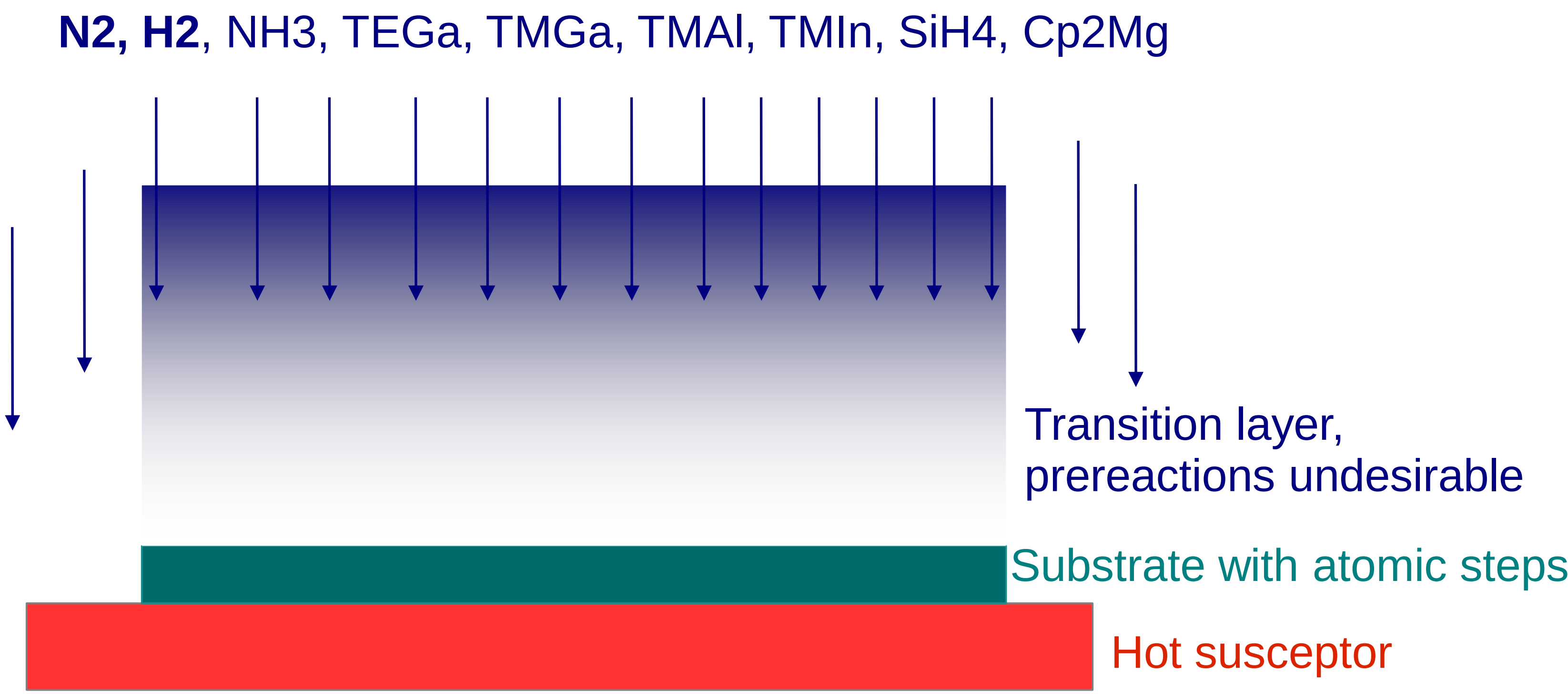
What do we wish to grow? For example, laser diode epi structure.







MOVPE growth of nitride semiconductors



As a result, we have a layer which has certain:
* chemical composition
* thickness
* morphology
* uniformity

TopGaN blue laser technology

unipress

1. Effectivness of atom incorporation into GaN, AlGaN, InGaN

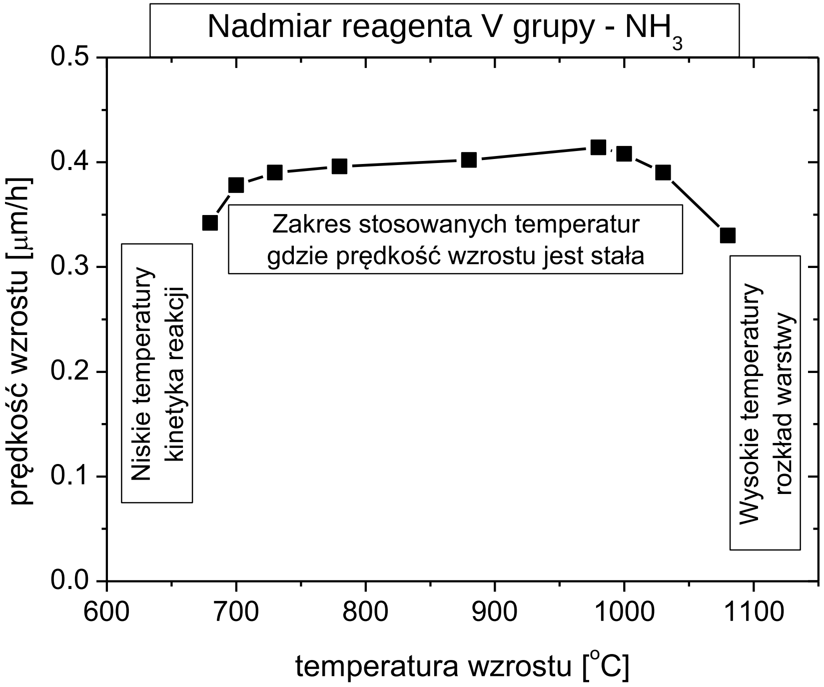
MOVPE reactors used

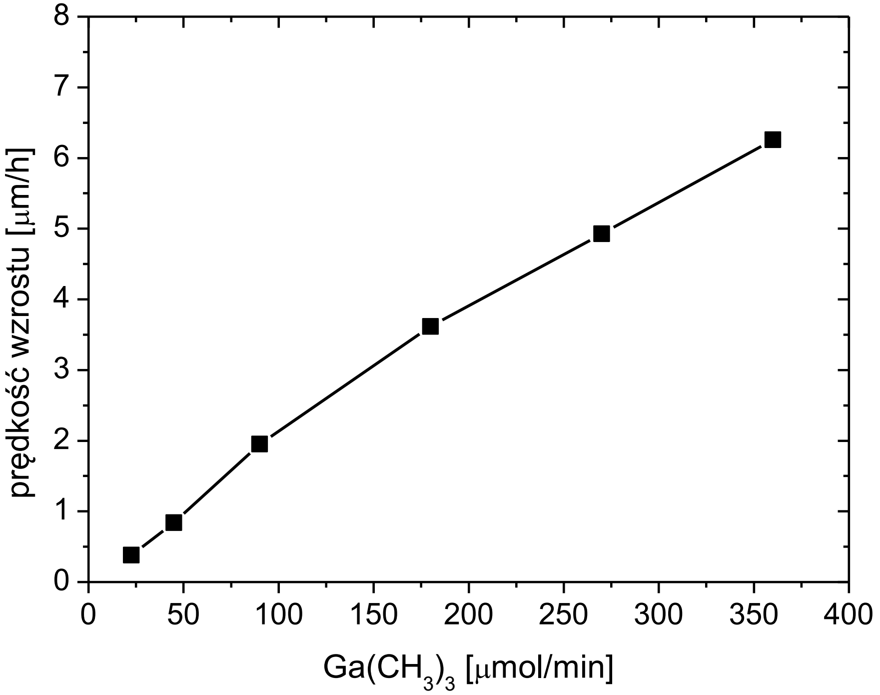
Home made (HM)
2000 growth runs

CCS Aixtron
4000 growth runs

High Pressure (HP)
200 growth runs

Effectivness of Ga incorporation into GaN vs temperature and TMGa flow in HM





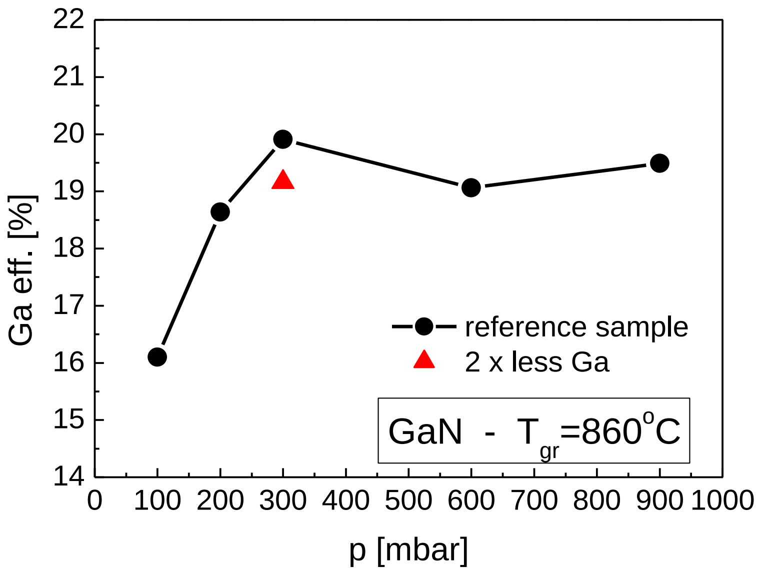
Growth rate proportional to TMGa or TEGa flow

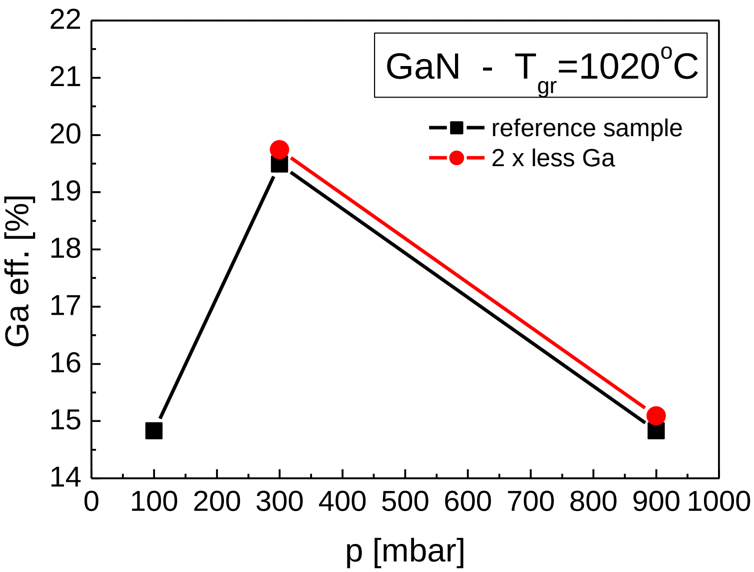
Low temperature – low ammonia decomposition

High temperature- decomposition

Effectivness of Ga incorporation into GaN vs pressure

Efficiency= number of atoms incorporated into the epi layer/ number of atoms in gas phase



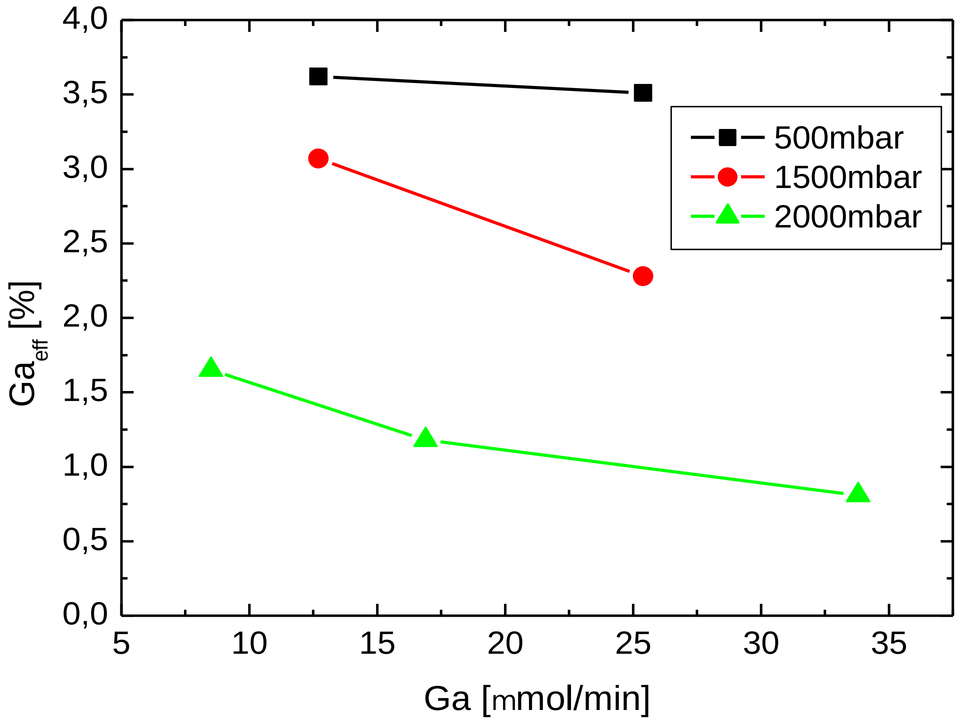


At low pressure, the Ga atoms are blown away from the surface.

At high pressure and temperature, the rate of prereactions increase which prevents Ga incorporation

Efficiency of Ga incorporation independent on amount of TEGa

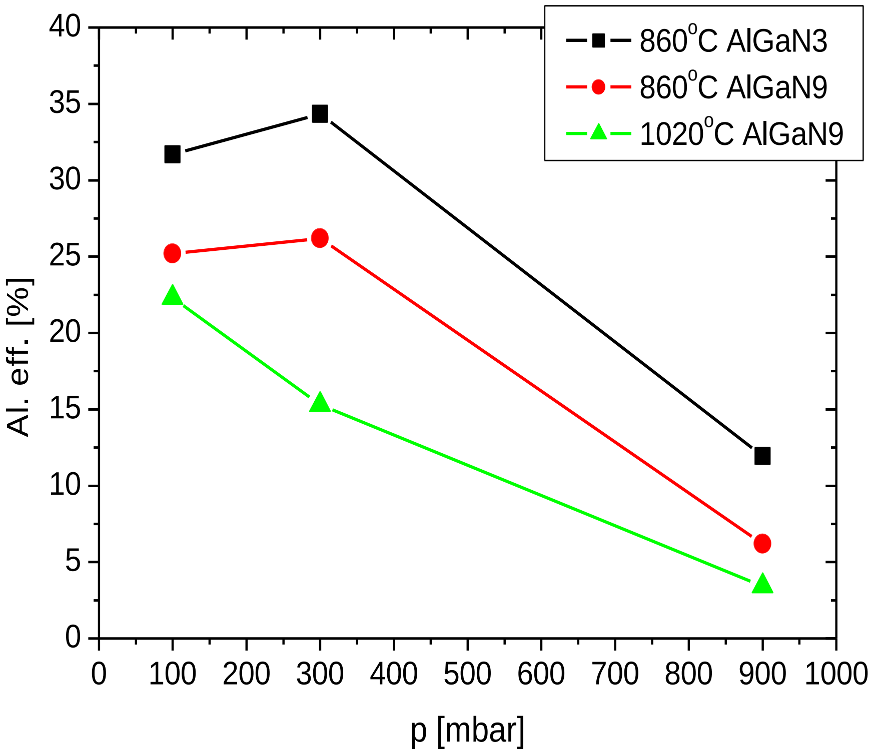
Efficiency of Ga incorporation into GaN in HP



Much lower efficiencies of Ga incorporation than in HM and CCS

At high pressure, prereactions lower the Ga-incorporation efficiency

Efficiency of Al incorporation into AlGaN in HM



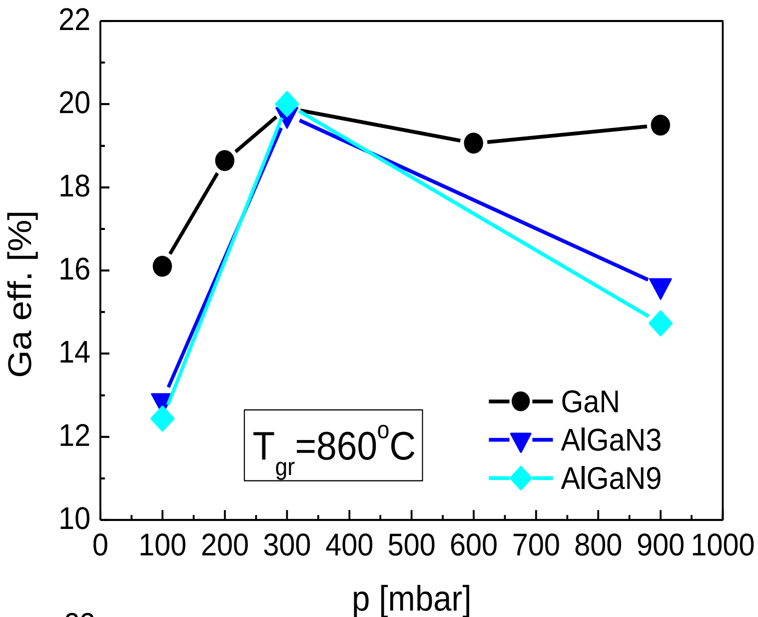
Efficiency of Al incorporation falls down with TMAl flow increase

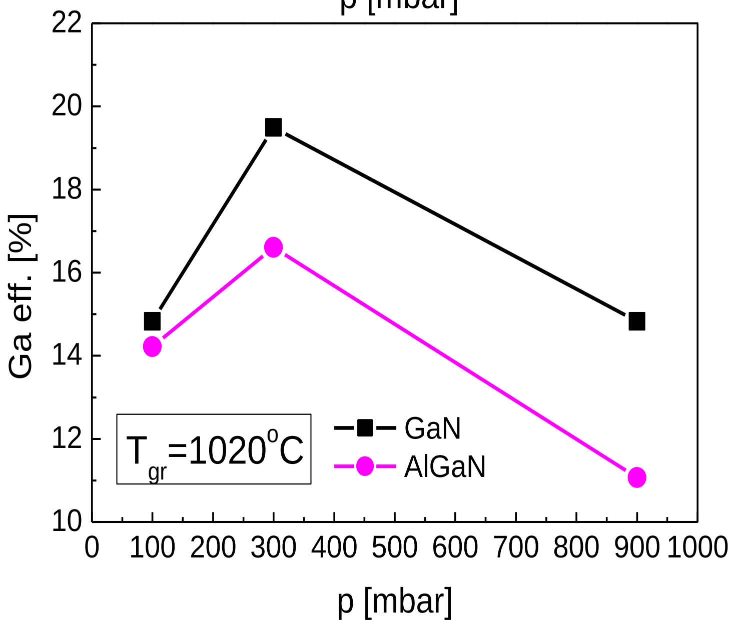
Prereactions rate higher than in the case of GaN

More prereactions at high temperature and pressure

3 sccm of TMAl
9 sccm of TMAl

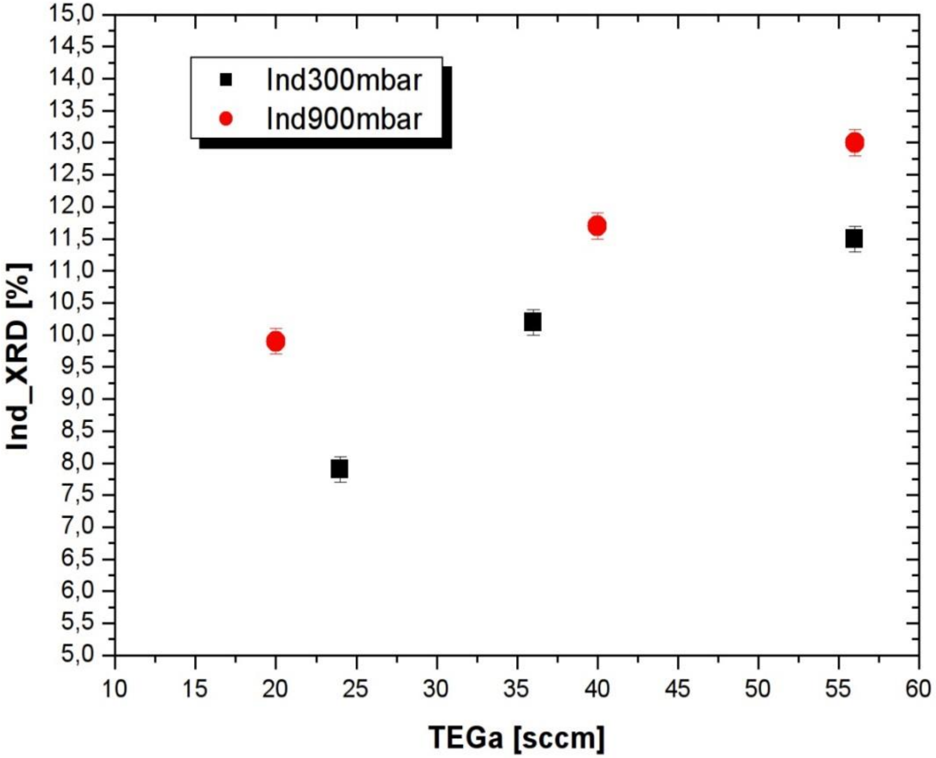
Efficiency of Ga incorporation into AlGaN in HM





Prereacted TMAl and NH3 molecules block Ga incorporation

Efficiency of In incorporation into InGaN versus TEGa (growth rate) flow in HM

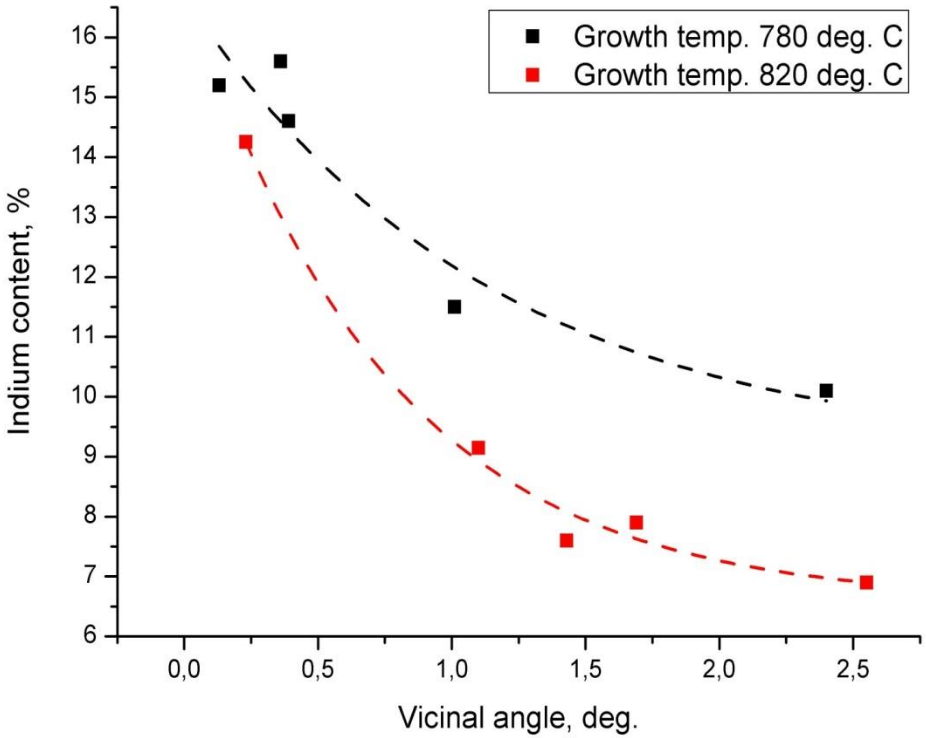


More Ga source in the gas phase, but more In in InGaN solid phase.

More indium at elevated pressure.

In atoms to be incorporated must be surrounded by Ga atoms

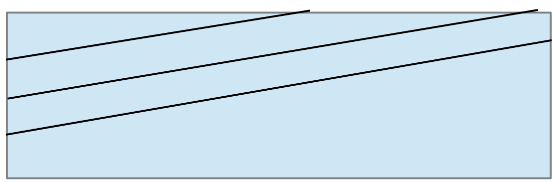
In incorporation into InGaN layers versus GaN substrate off-orientation

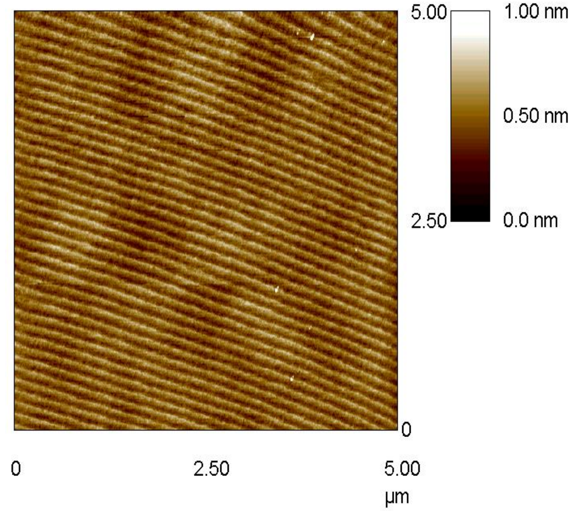


If we have bad morphology (steps are not identical), we deal with In inhomogeneous incorporation

GaN substrate off-orientation

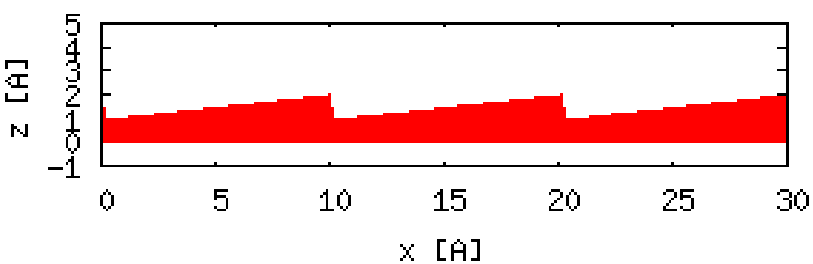
- The steps flow slower
- **Many AlGaN and InGaN parameters are strongly influnced**

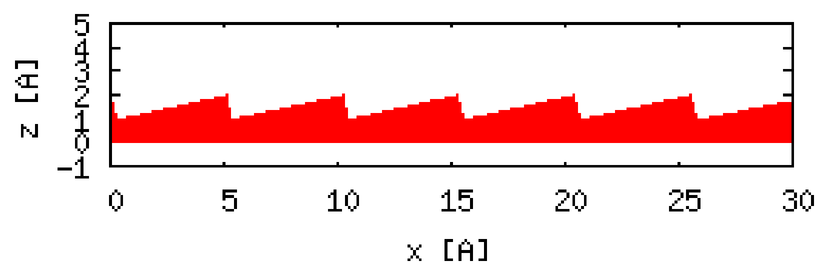




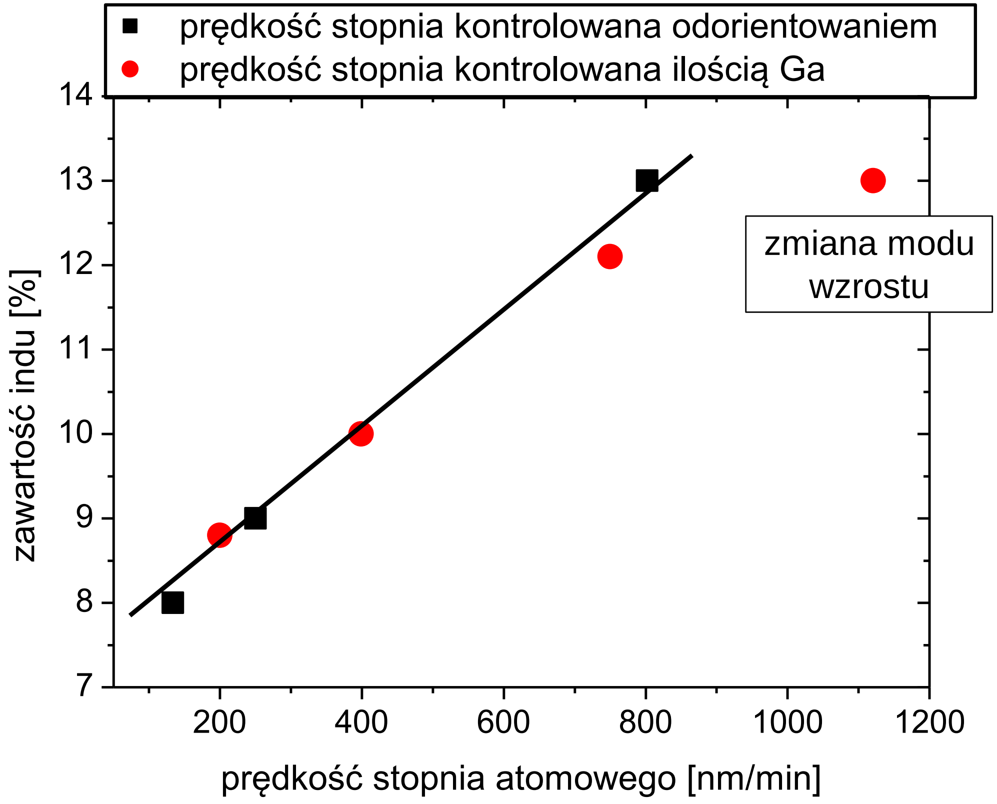
Low misorientation - fast atomic steps

Higher misorientation - slower atomic steps

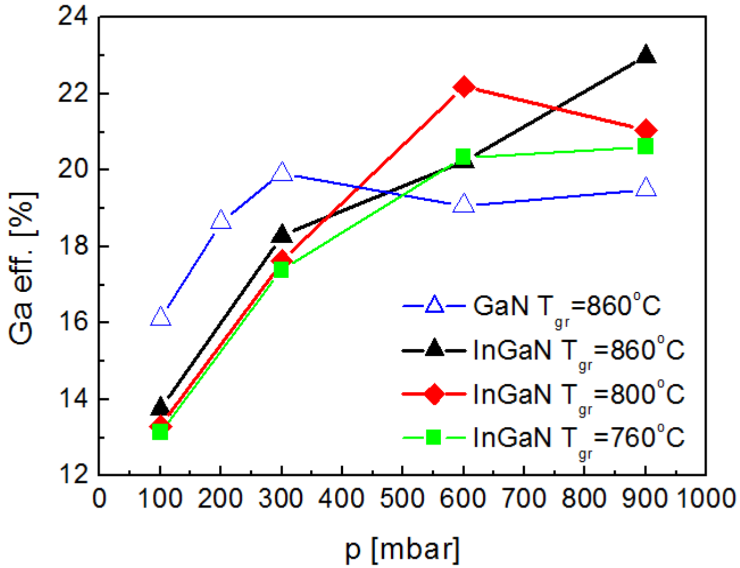


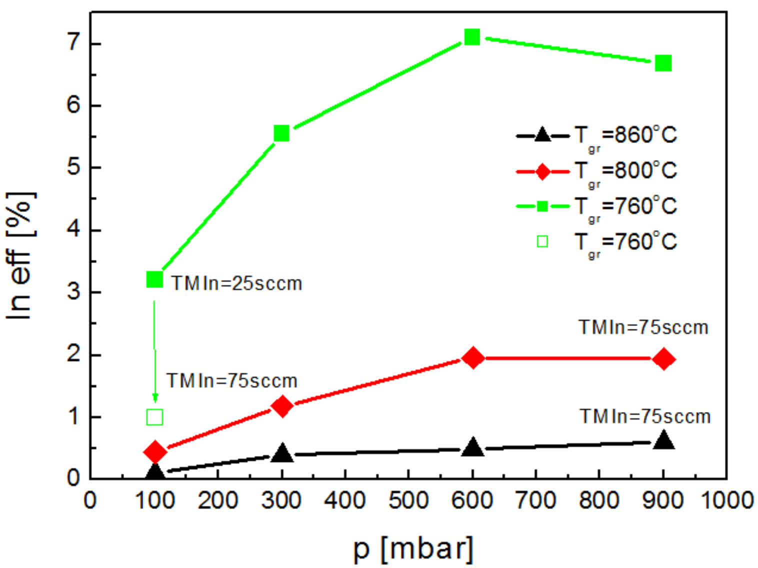


In incorporation into InGaN versus velocity of the steps in step-flow growth



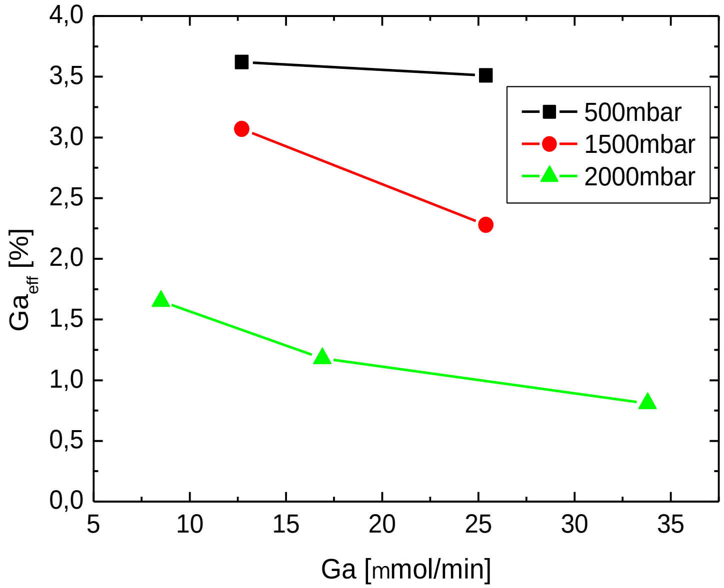
Efficiency of Ga and In incorporation into InGaN in HM

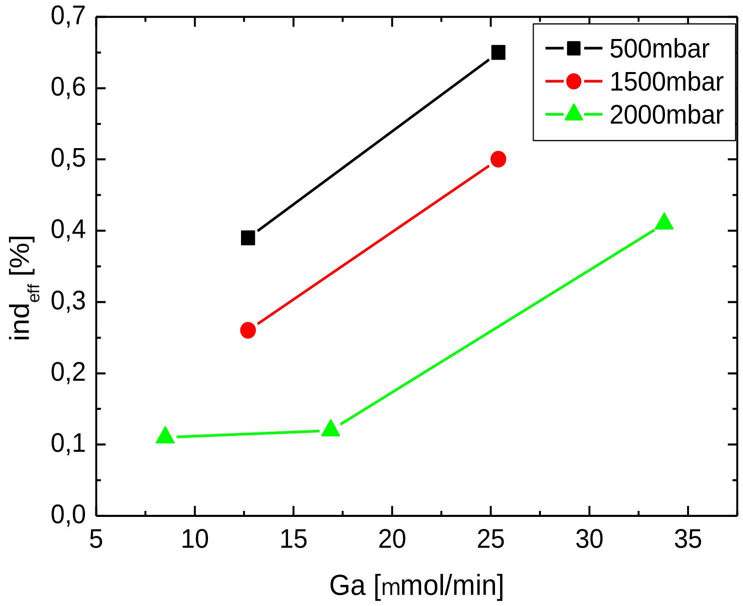




Indium increases Ga incorporation.
In incorporation efficiency increases for:
*** lower TMIn-flow**
*** lower temperature**
*** higher pressure (seems to be a maximum)**

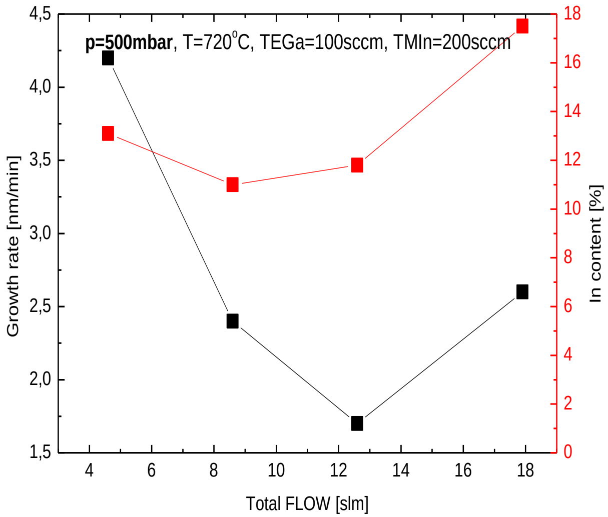
Efficiency of Ga and In incorporation into InGaN in HP



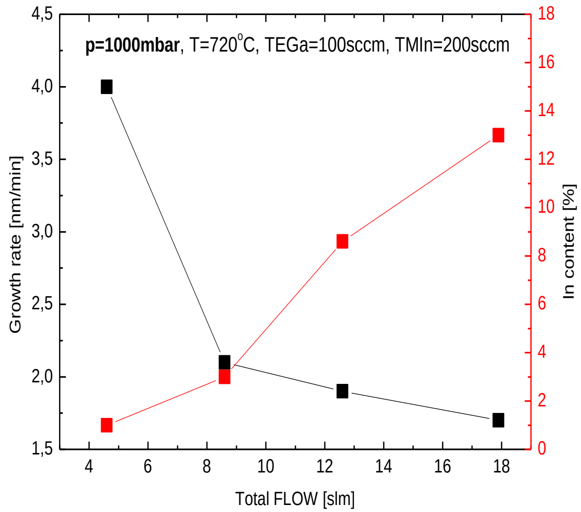


Prereactions in HP reactor- main source of troubles

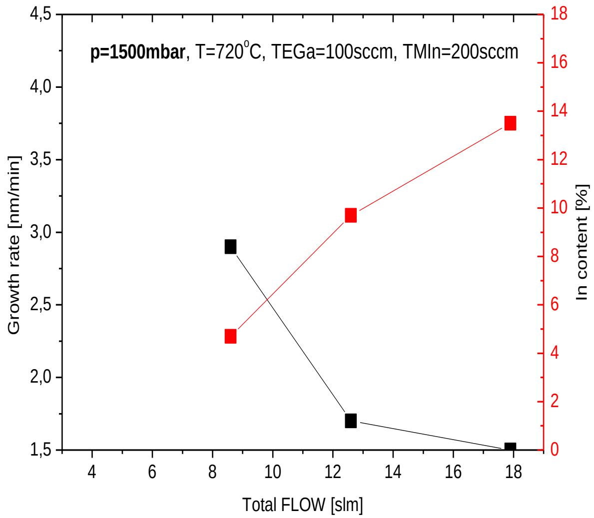
Influence of total flow on the InGaN growth rate and In incorporation in HP



500 mbar



1000 mbar

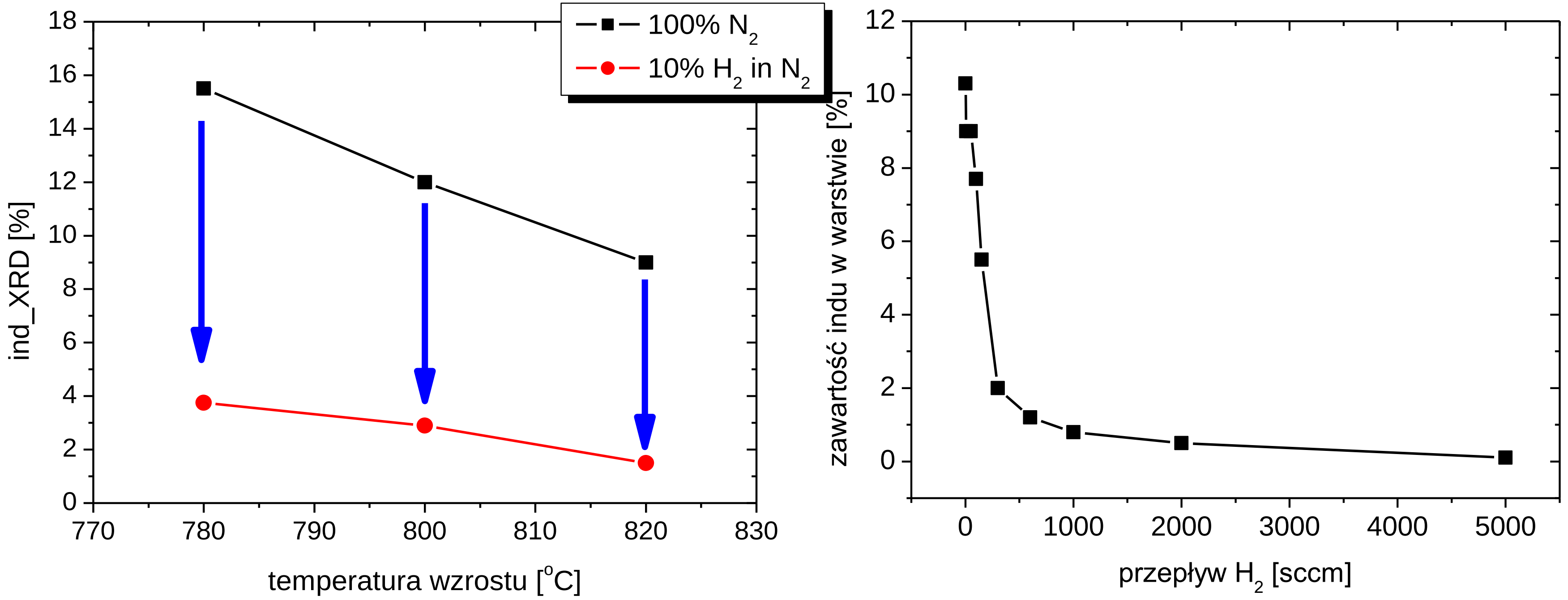


1500 mbar

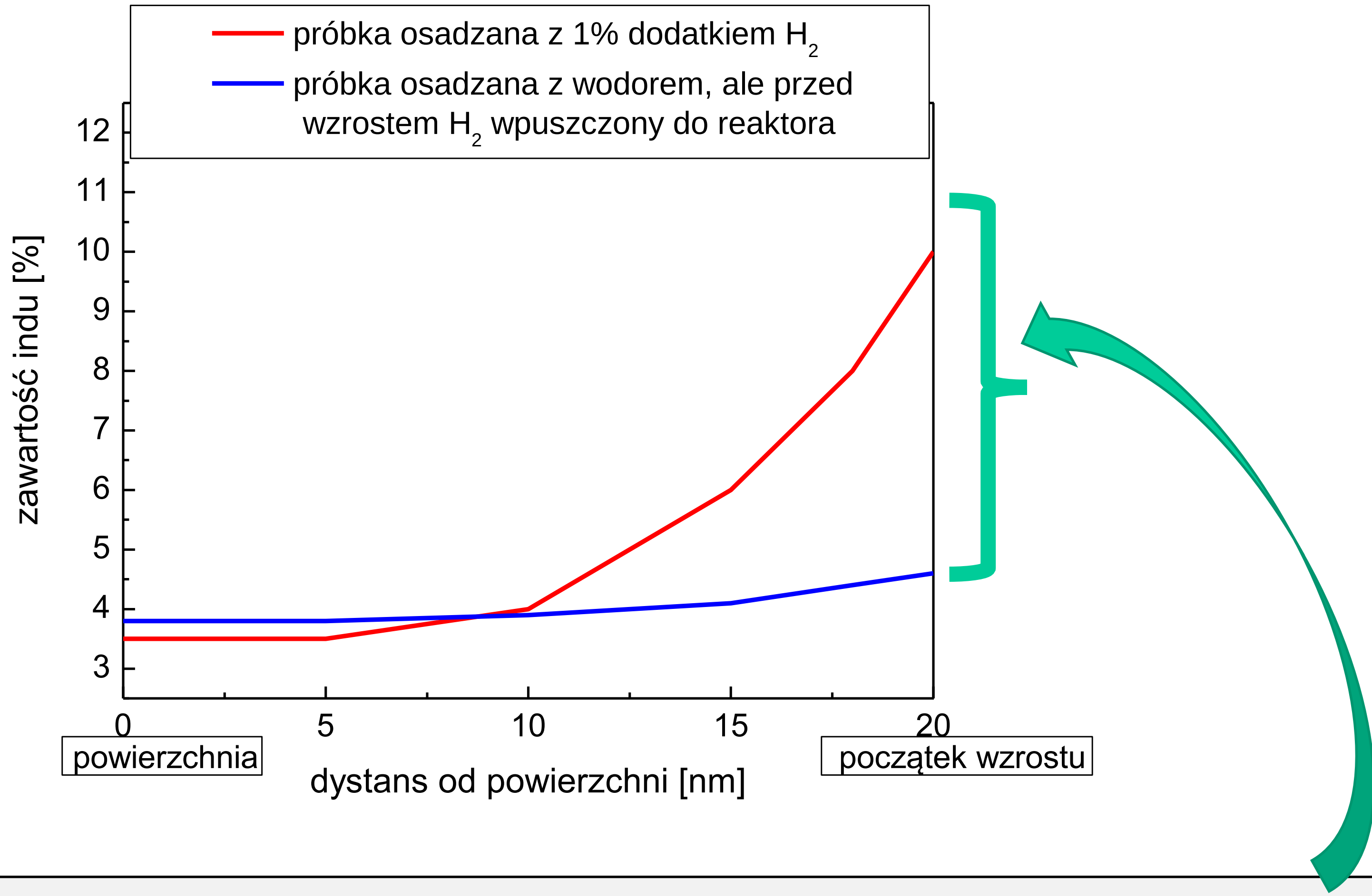
Growth rate decreases with total flow- TEGa and TMIn are blown away more efficiently

In content increases. Lower real temperature? Different NH3/NH2 on the surface? Lower prereaction rate?

Influence of hydrogen used in the carrier gas

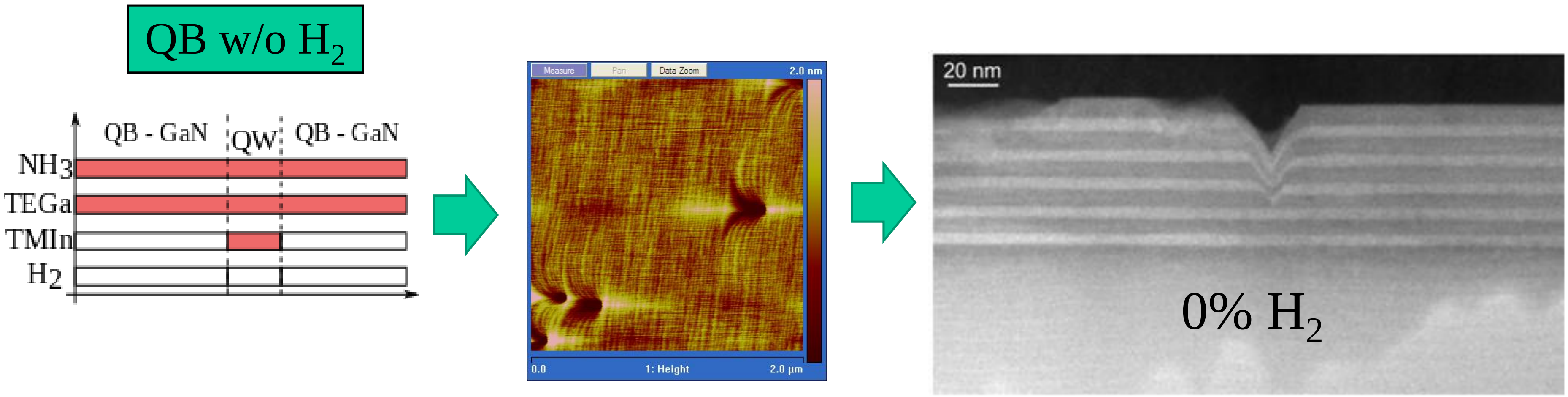


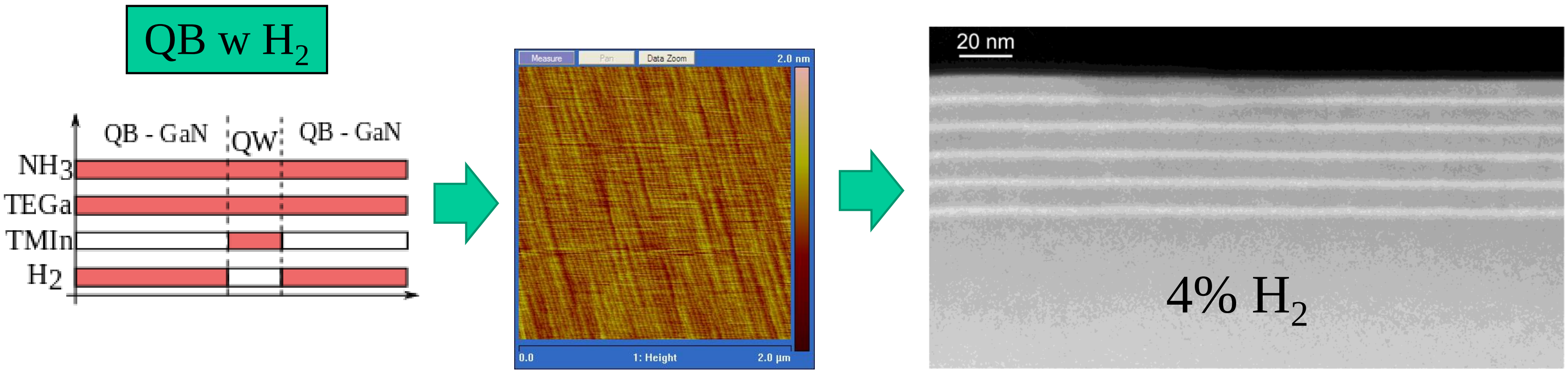
Gradient of In content in InGaN layers grown with H2 in the carrier gas



Hydrogen passivates the surface and In is not incorporated

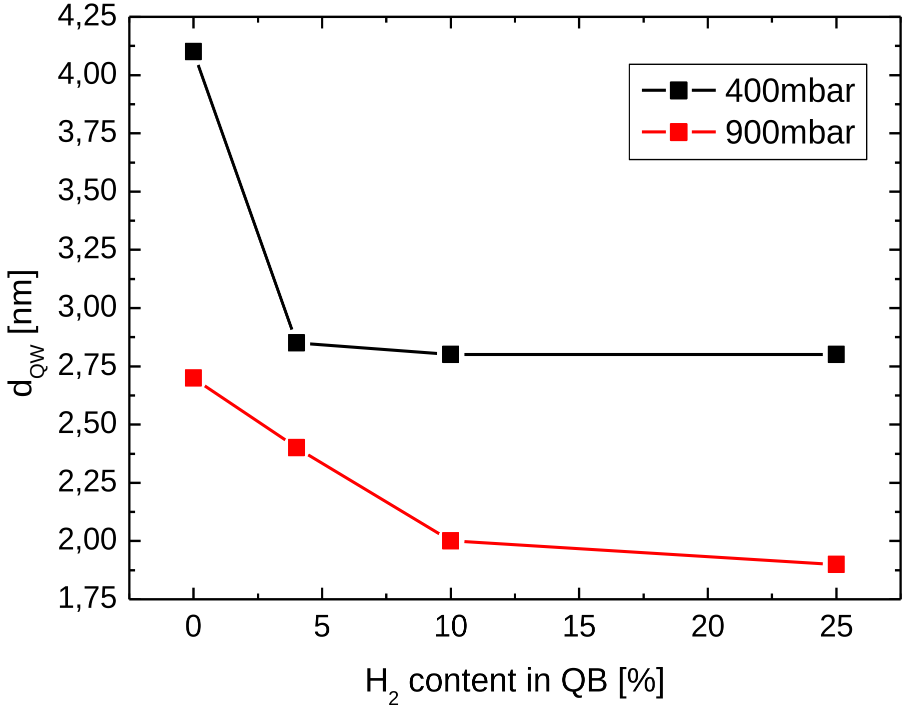
Growth of InGaN QWs with QBs grown with hydrogen

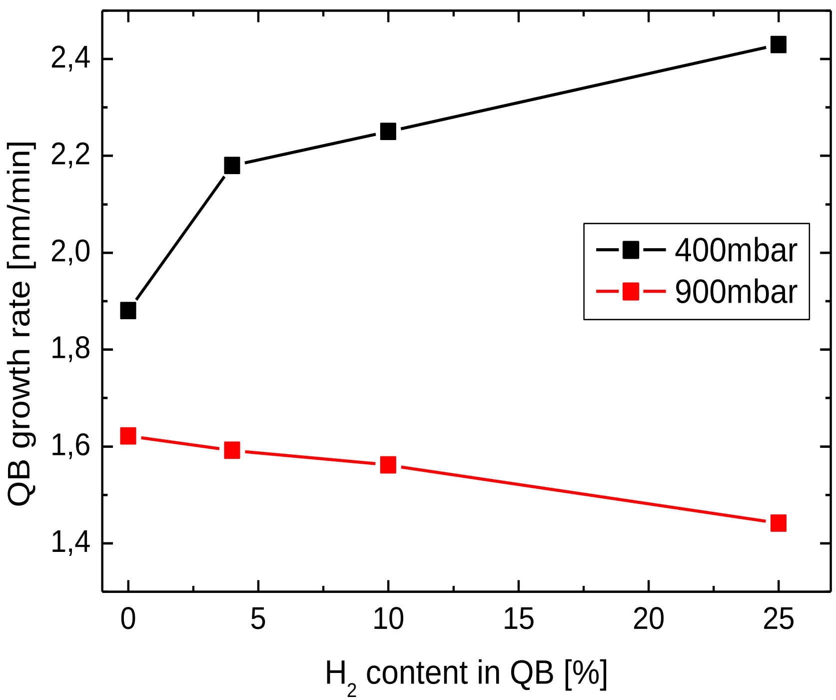




Hydrogen eliminates defects but influences also the QWs

Influence of hydrogen used in the carrier gas during GaN barrier growth in CCS

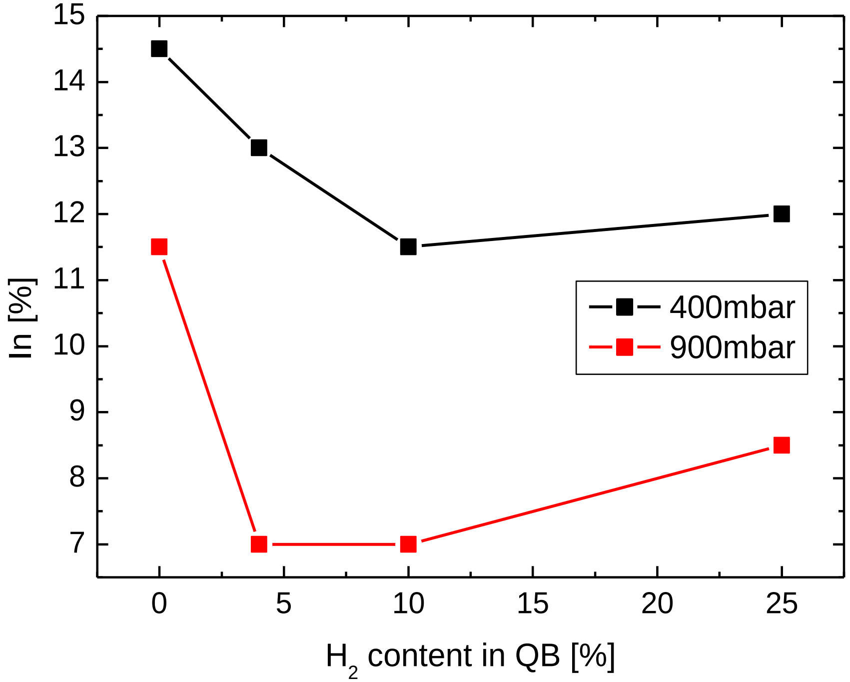


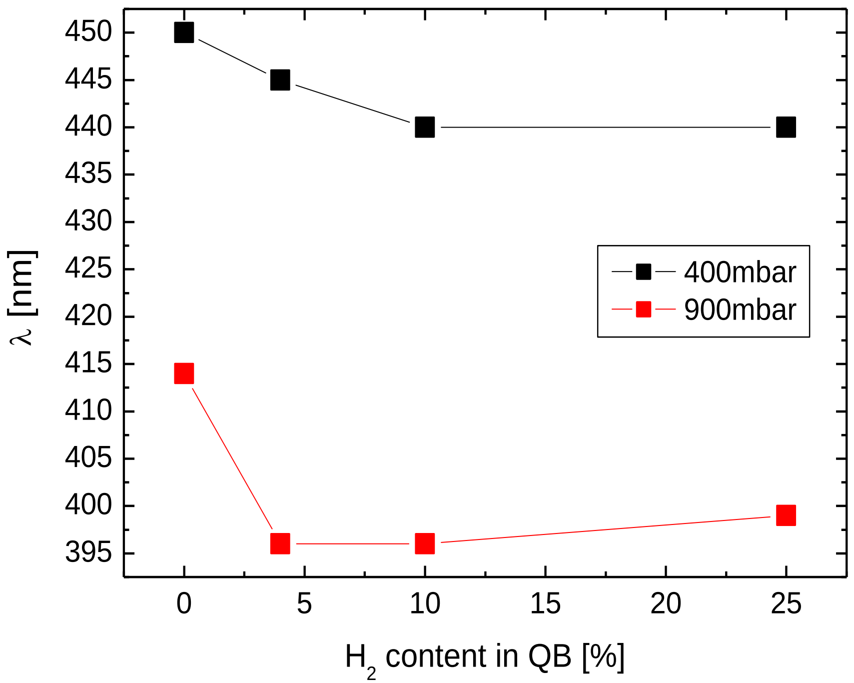


Hydrogen used in QB growth etches off InGaN QW more efficiently at high pressure

Hydrogen increases the growth rate of GaN (QB) at low pressure (???), deacreses at higher pressure.

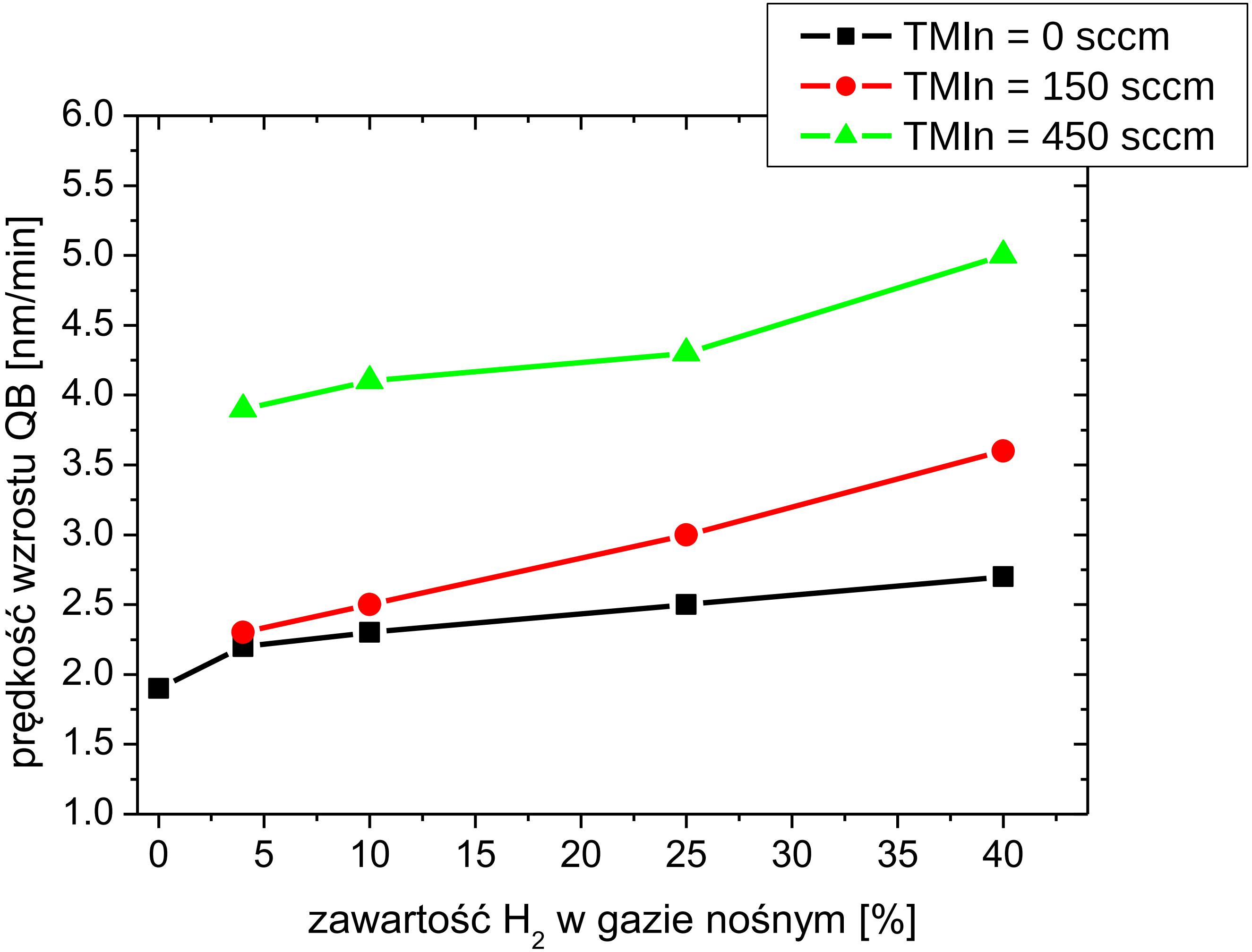
Influence of hydrogen used in the carrier gas during GaN barrier growth in CCS





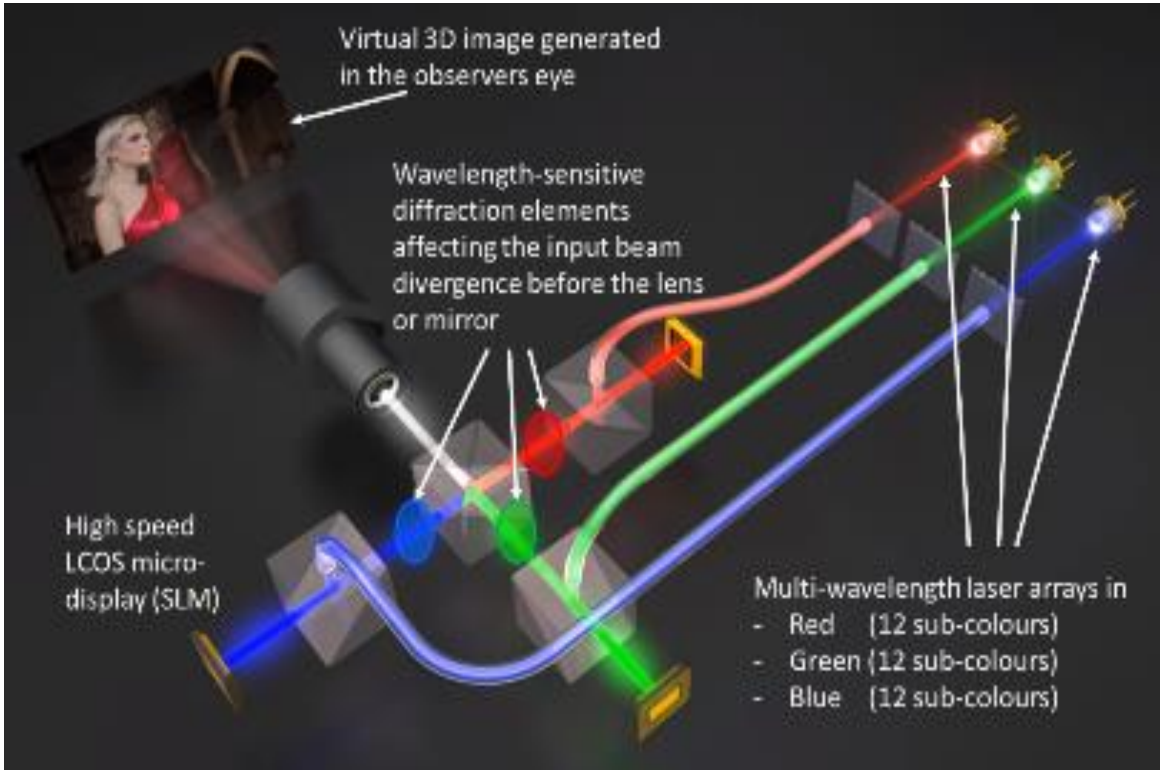
Hydrogen used in QB growth etches In off InGaN QW more efficiently at high pressure

Influence of hydrogen and H2 on Ga incorporation



Effectivness of Ga incorporation in CCS

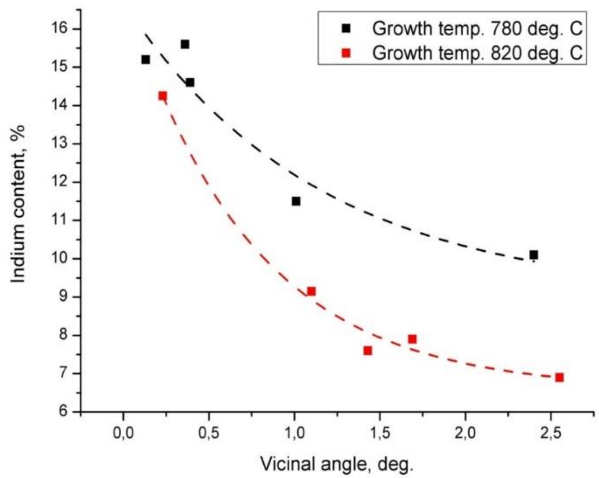
3-D Projectors without goggles- Holy Grail of optoelectronics

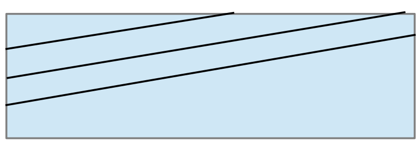


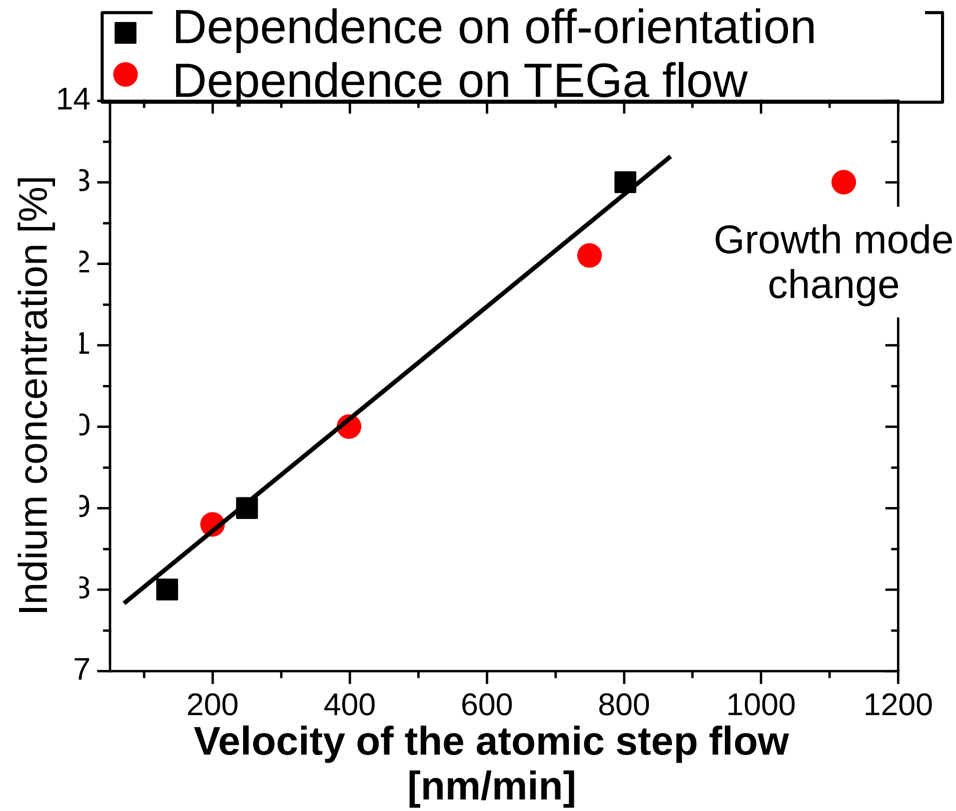
Nitrides:
Blue 450-460 nm, step 1 nm
Green 520-530 nm, step 1 nm

Arsenides/phosphides
Red 630-640 nm, step 1 nm

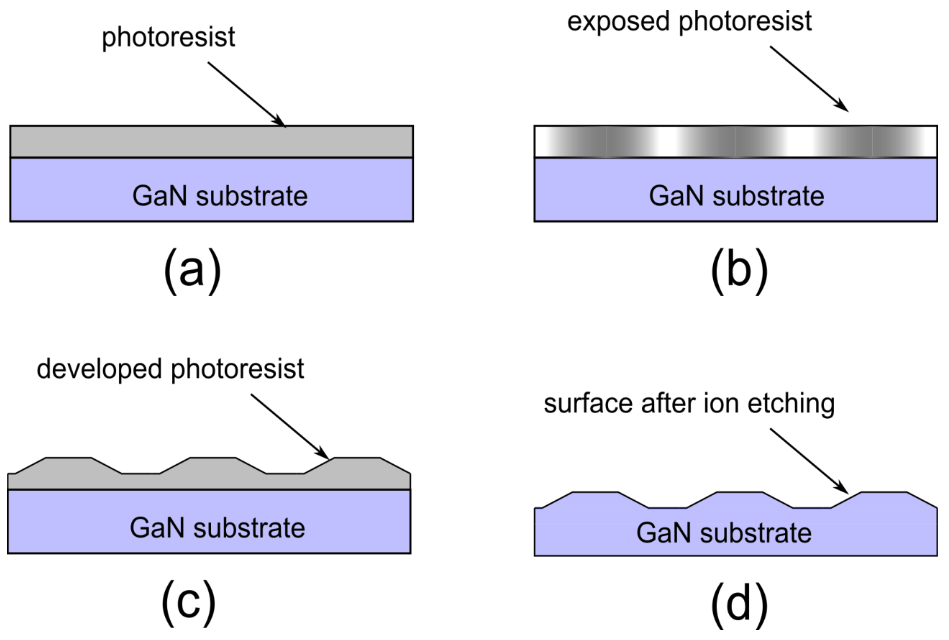
In incorporation into InGaN layers versus GaN substrate off-orientation or growth rate

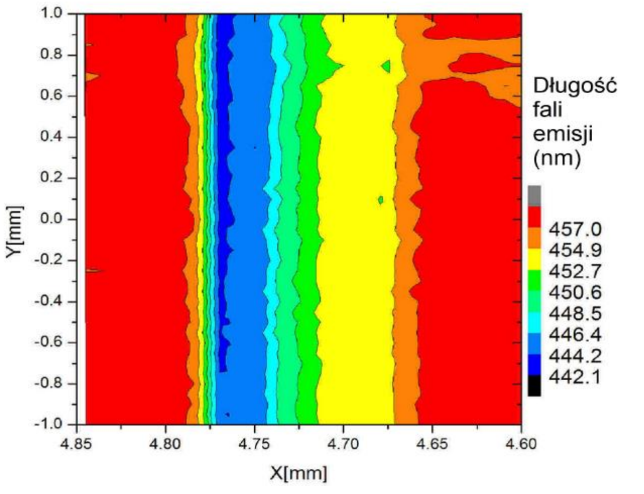






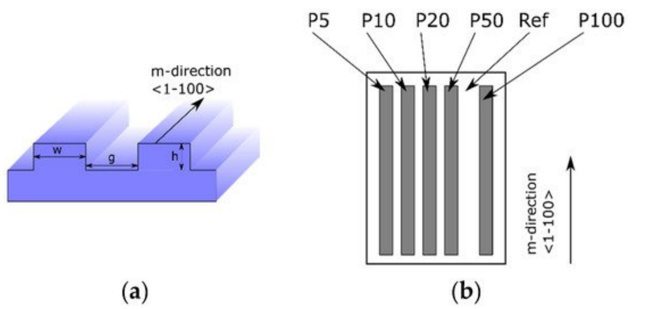
Technology 1: Lateral patterning



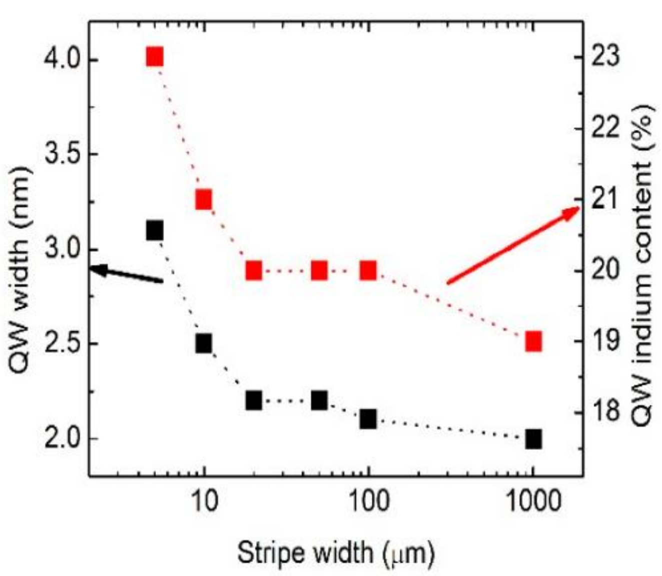


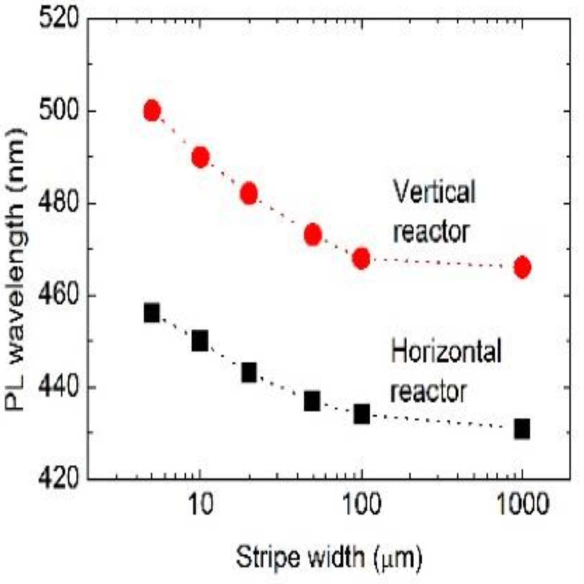
M. Sarzynski idea
Patented by TopGaN/Unipress

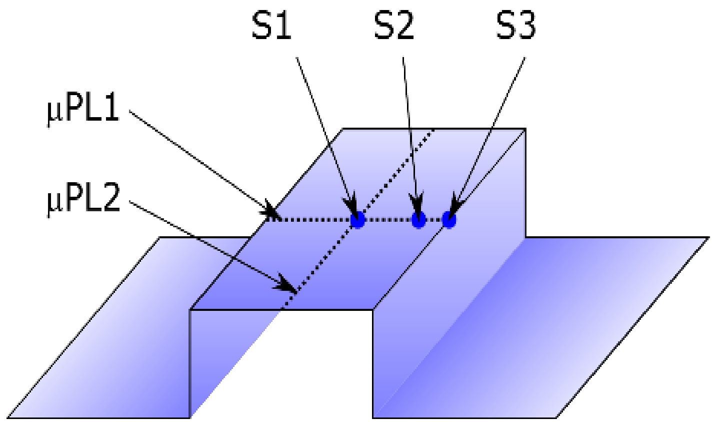
Technology 2. Growth of InGaN QWs on narrow stripes.



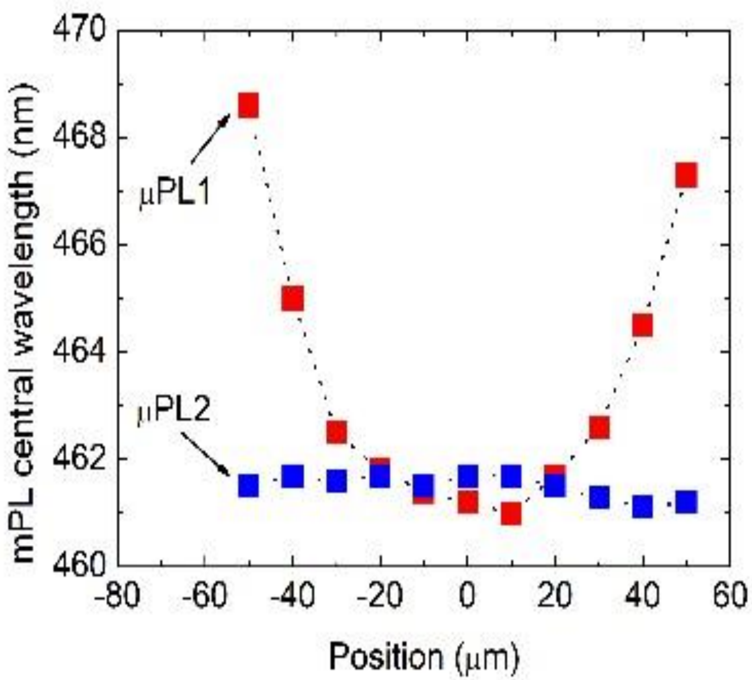
(a) (b)







Faster growth at the edges, more indium incorporated

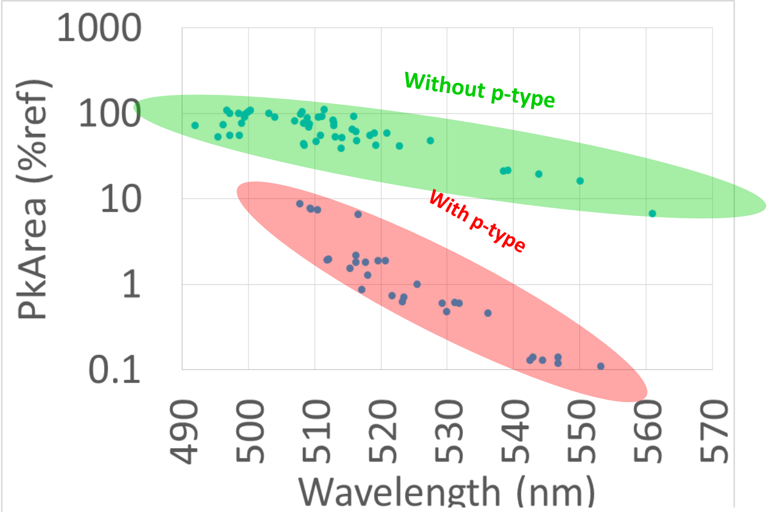


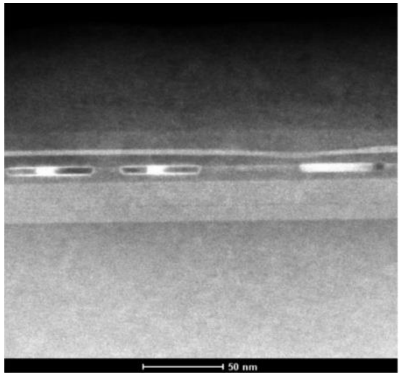
Both technology 1 and 2 of blue multicolour arrays attract a big interest as they may lead to 3D projectors.

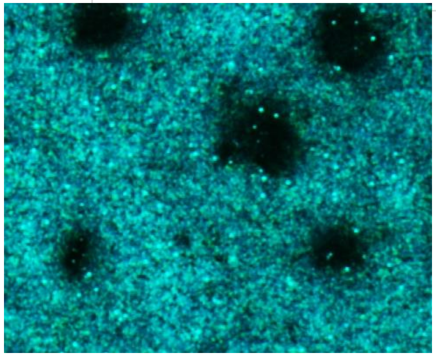
Decomposition and homogenization of InGaN QWs at high temperature

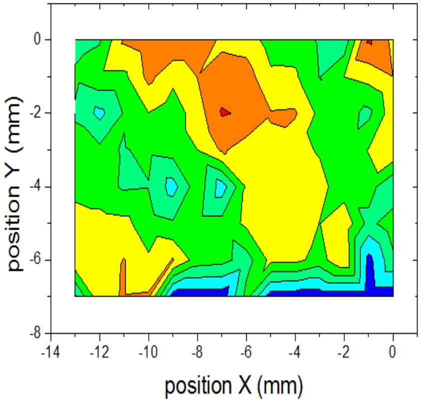
Layer	Growth temperature
GaN:Mg	T_{Gr} = XXXX°C
AlGaN:Mg	
GaN:Mg	
EBL - AlGaN:Mg	
Cap – GaN	
Cap – GaN	T_{Gr} QW < 740°C T_{Gr} QB > 740°C For In content > 15%
QW - InGaN	
QB – GaN	
InGaN	
GaN	T_{Gr} = 1000°C
AlGaN:Si	
GaN:Si	
Substrate	

InGaN MQW decomposition









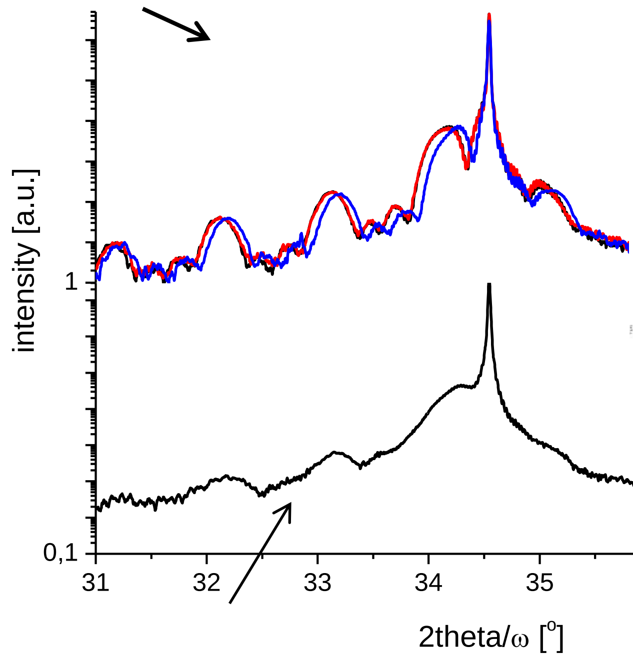
TEM: nanometer scale, Fluorescent microscopy: micrometers, MicroPL: m

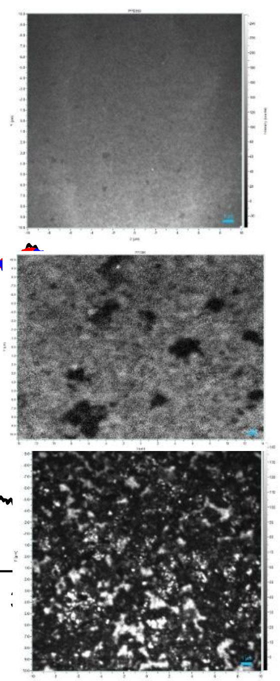
Changes of the MQWs during p-type growth at high temperature: samples on sapphire

HR-XRD measurements of LED structures:

CL

XRD:





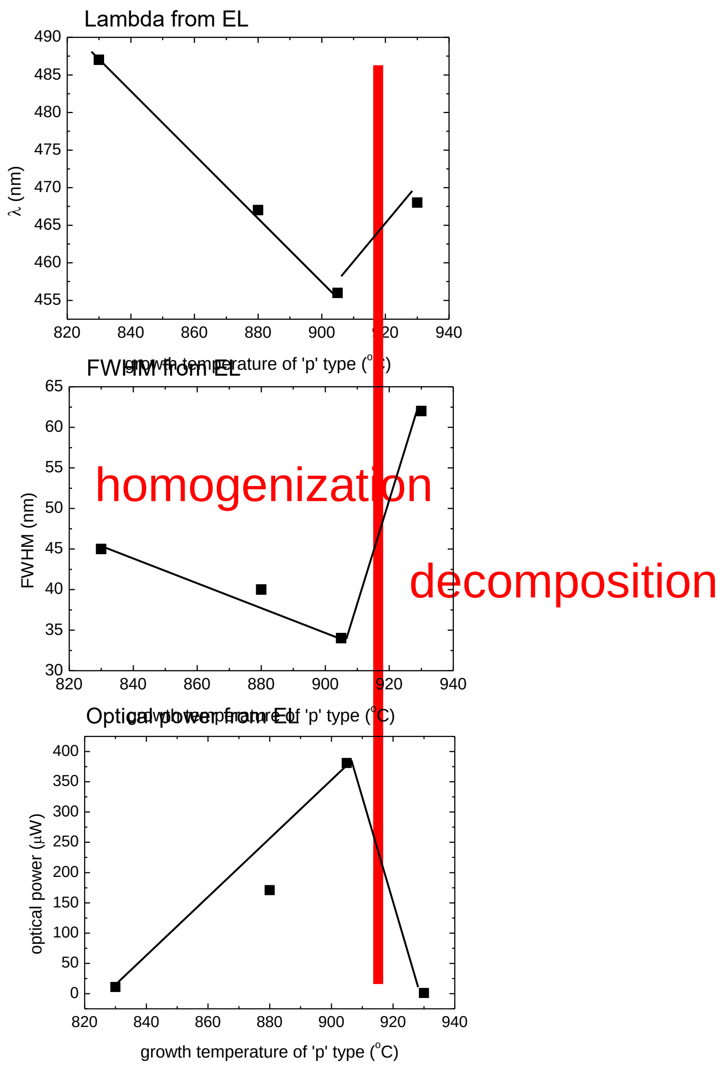
T=830°C In – 18%

T=880°C In – 18%

T=905°C In – 16%

T=930°C In – ?

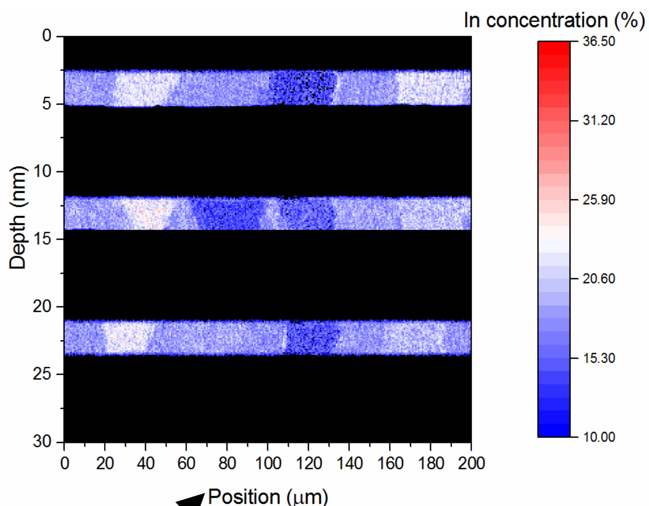
At high temperature satellite peaks becomes much more broader and disappear : QWs degradation occurs



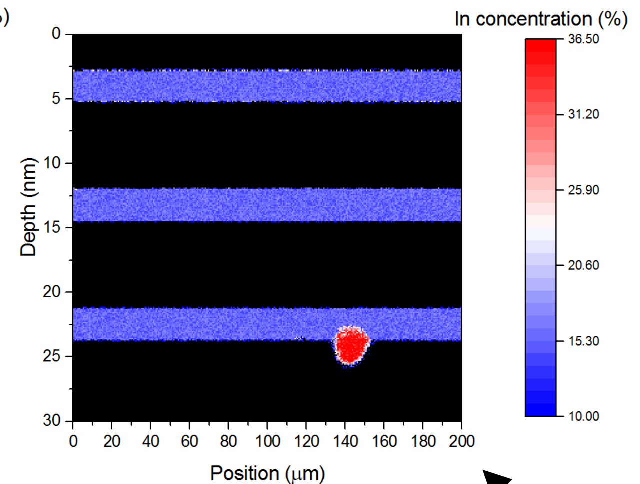
For samples on sapphire (high dislocation density) we are able to homogenize InGaN QWs by growing p-type at high temperature.

If this temperature is too high, we deal with a catastrophic damage

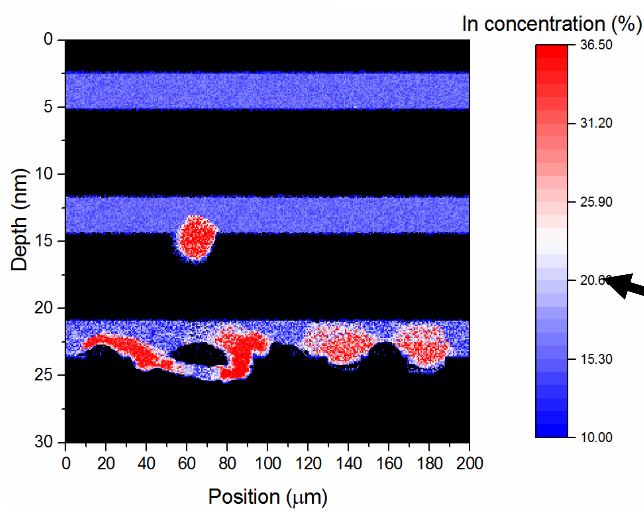
SIMS data of In-content



as grown

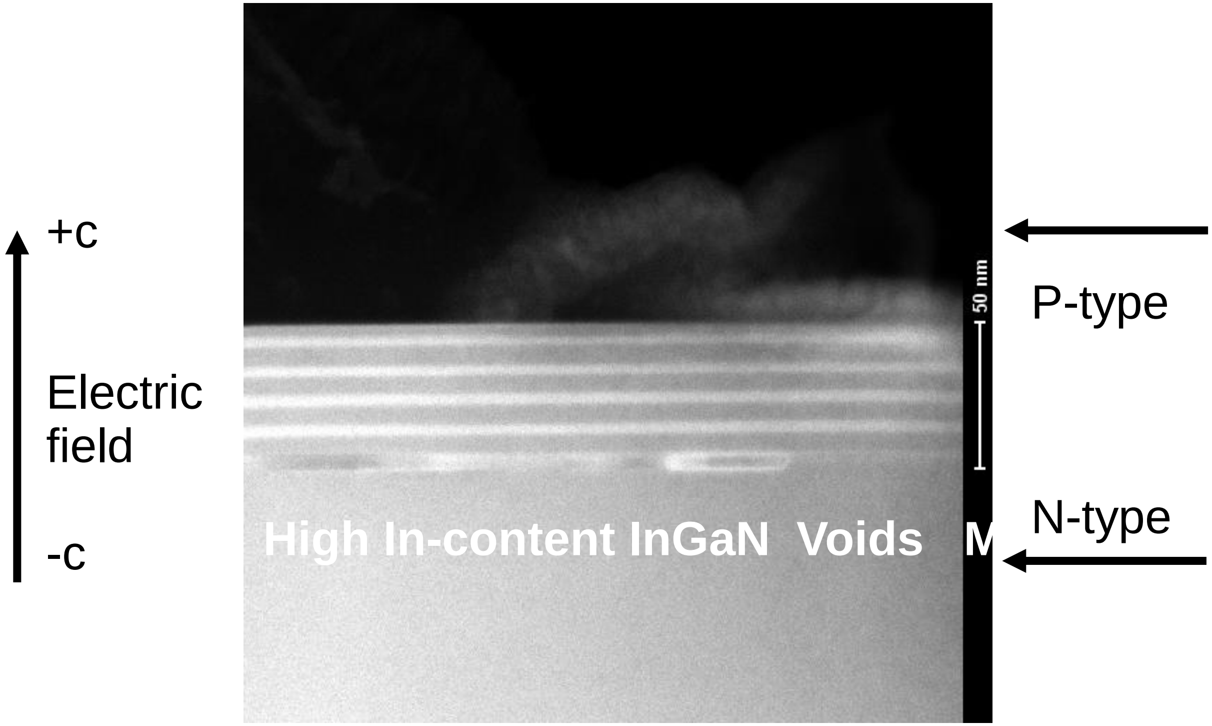


Homogenized
905ºC



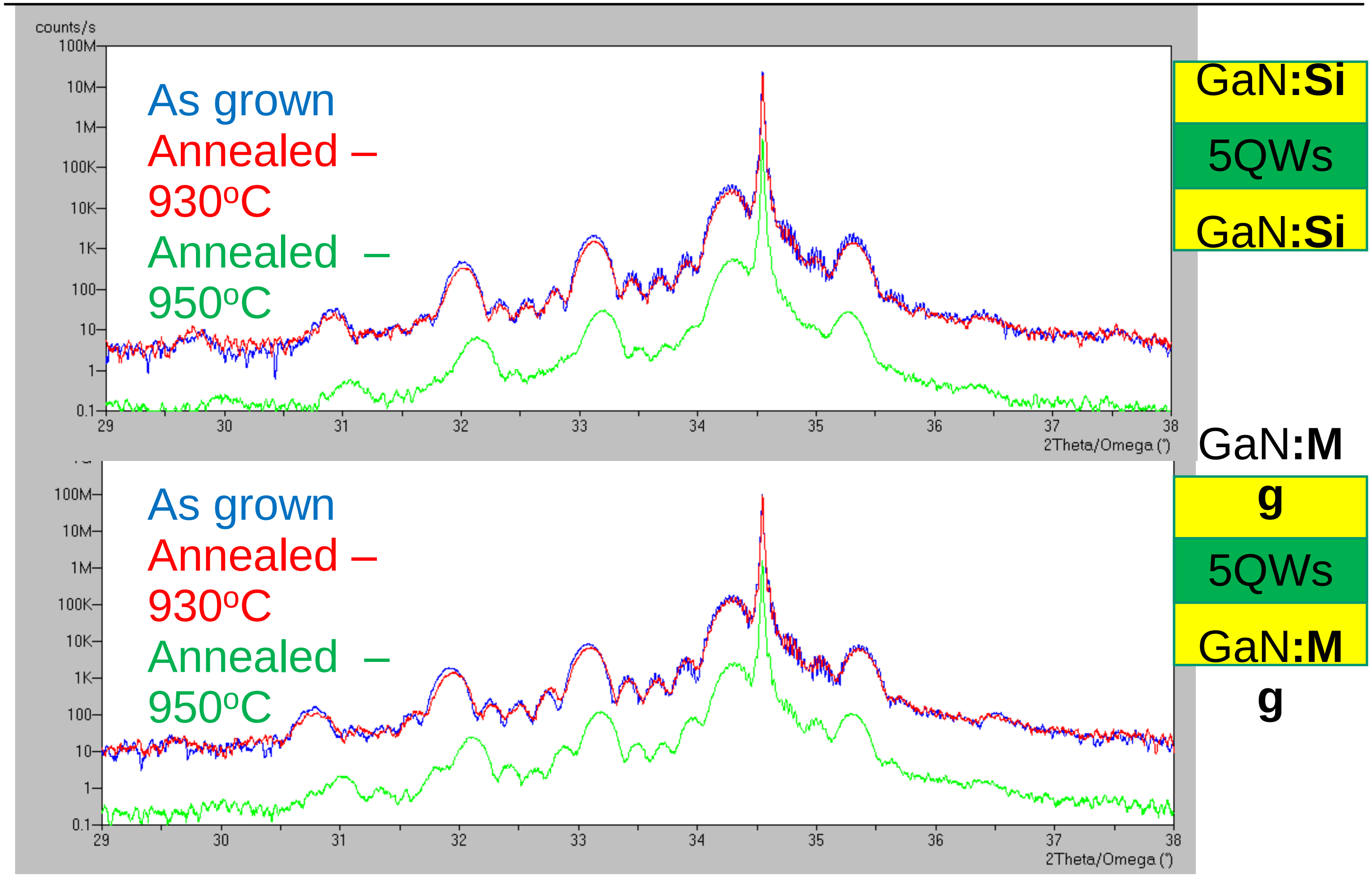
Decomposed
930ºC

Why does the decomposition start from the first QW?



Diiferent doping below and above the InGaN/GaN MQWs

5QWs - (460 nm) - 17%In

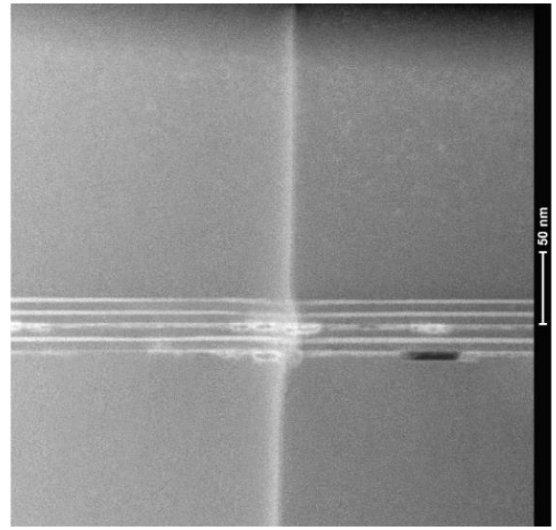


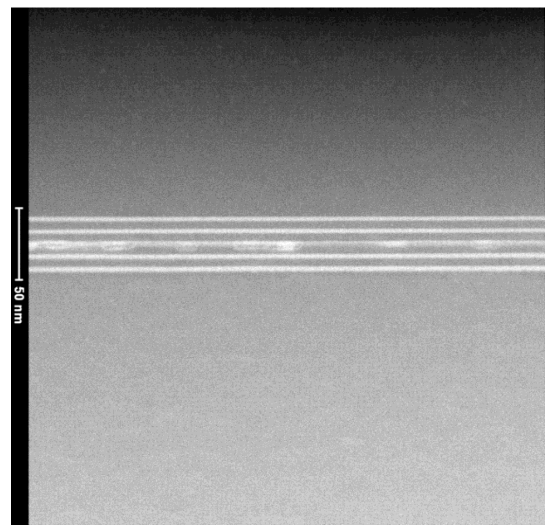
After annealing at 950ºC

No decomposition from the top

Electric field
driven diffusion?
Yes!

GaN:**Si**
5QWs
GaN:**Si**





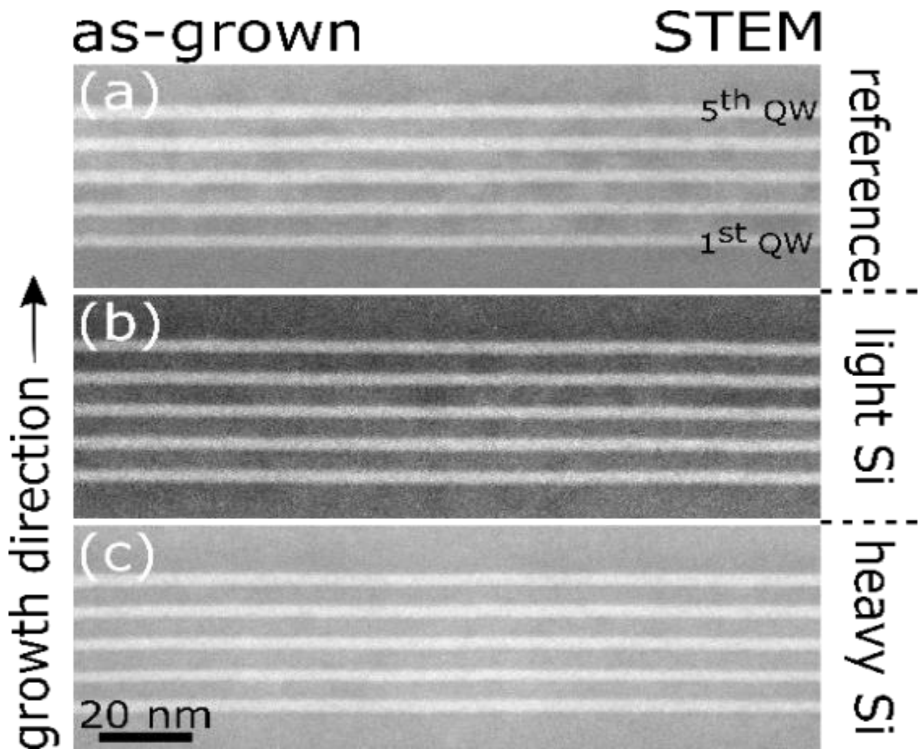
No decomposition
above and below
GaN:Mg

GaN:**Mg**
5QWs
GaN:**Mg**

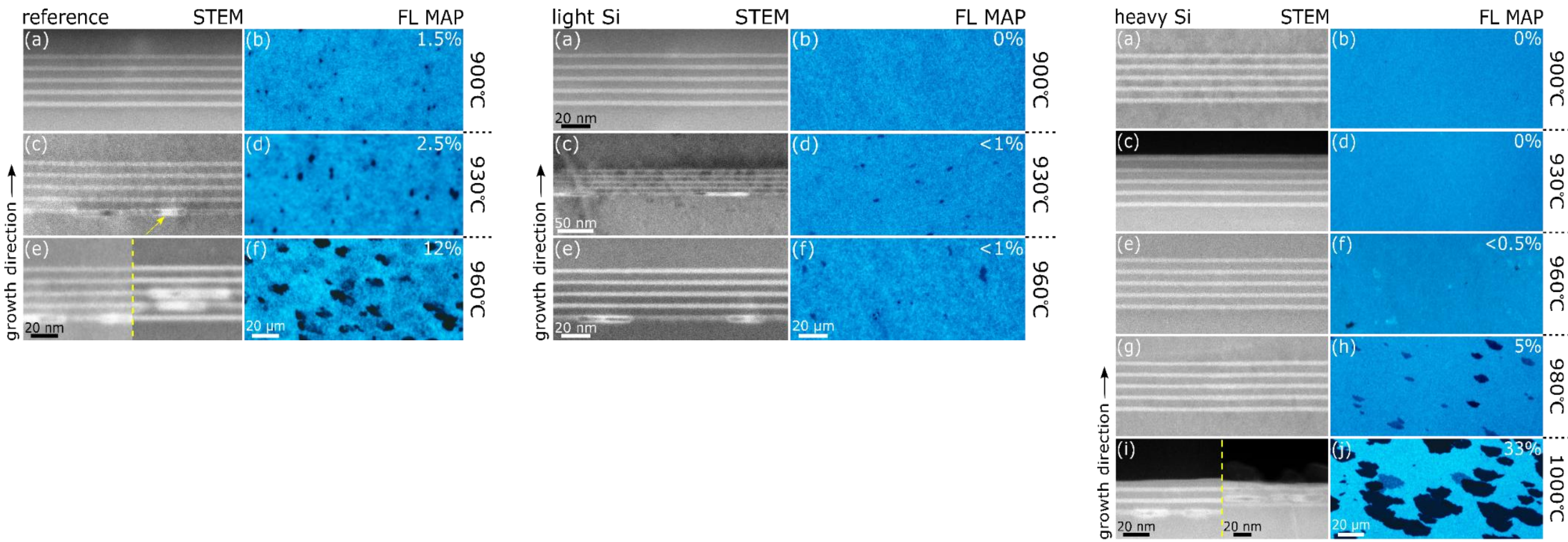
Ga-vacancies?
Yes!

Influence of Si-doping on InGaN QW decomposition

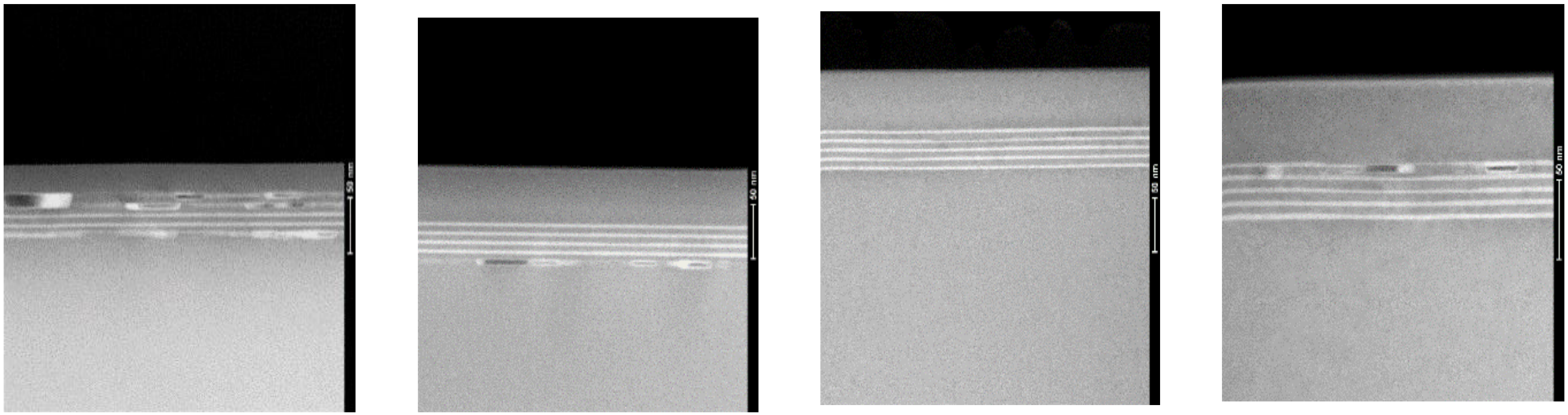
structure	X doping in BLs
reference	unintentional
light Si	**Si** 10^{18} cm^{-3}
heavy Si	**Si** 10^{19} cm^{-3}



High Si doping: decrease of V(Ga) mobility



Influence of annealing atmosphere



A *B* *C* *D*

TEM topographs of InGaN/GaN QWs after annealing for 30 min. at 940^{o}C and

A: in NH_3+H_2 atmosphere,

B: in TEGa+NH_3+H_2 ,

C: in TEGa+NH_3+H_2 , the barrier before the first QW doped with Si,

D: in NH_3+H_2, , the barrier before the first QW doped with Si.

Closing remarks

1. The growth parameters in MOVPE are not independent to each other.
2. Growth is different in different reactors.
3. Incorporation of atoms is still not well understood.
4. The properties of the layers depend what has been grown below them and above them.