N coordination chemistry in diluted InGaAs nitride layers

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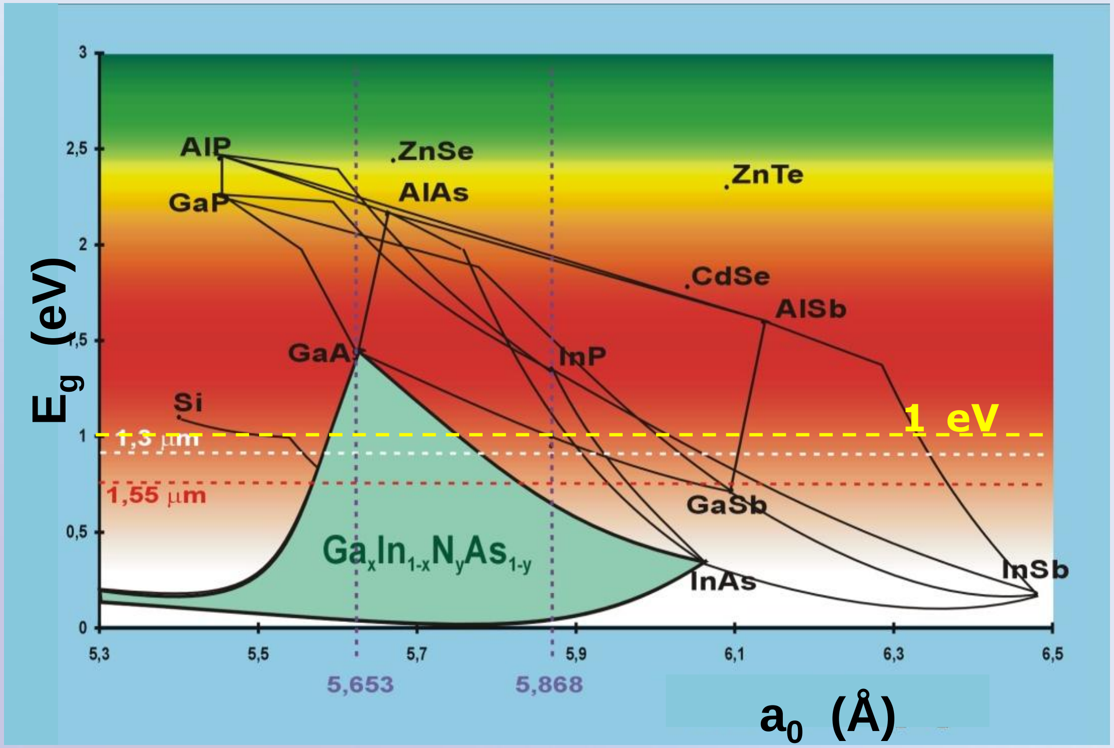
Motivation

Lattice matched to GaAs
Band gap tunability

Unusual properties:

- Huge band gap bowing coefficient
- Band gap reduction with small amount of N
- Large conduction band offset (**ΔE_c > 300 meV**)



Courtesy of Prof. M. Tłaczała

Applications:

- promising material for **IR lasers** and **HBT**
- **VCSELs and RCE devices**
- **high efficiency multi-junction solar cells** - $In_{0.09}Ga_{0.91}As_{0.97}N_{0.03}$ lattice-matched to GaAs and Ge substrate $\rightarrow$ Eg ≈1 eV

Technological problems:

- **Large miscibility gap between GaAs and GaN**
- **Large amounts of point defects:** vacances, antisites, interstitials
- **High concentration of impurities:** oxygen, carbon, hydrogen (MOVPE)
- **Large amounts of examination methods are needed** for proper characterisation !

Sample description

Growth method

- AP MOVPE
- AIX200 R&D Aixtron horizontal reactor
- organic sources: AsH_3 (10% in H_2), TMGa, TMIn, TBHy
- H_2 as a carrier gas
- (100)-oriented n-doped GaAs substrate

Growth parameters

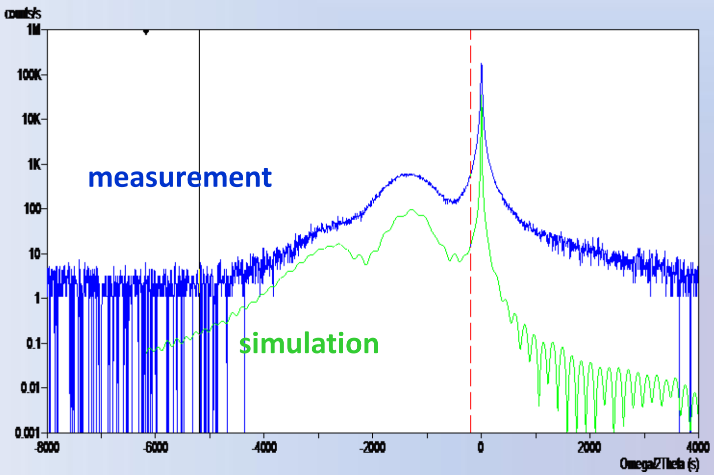
- Organic source temperatures: **T_{TMGa} = -10°C, T_{TMIn} = 20°C, T_{TBHy} = 30°C**
- **V_{AsH3} = 50 ml/ min** (InGaAsN)
- Growth temperature: **T_g = 575°C, 585°C**
- Growth time: **t_g = 30 min, 10 min**
- Annealing temperature and time: **T_g = 700°C, t_g = 5 min**

NI52n	NI52nA	NI74n
$In_yGa_{1-y}As_{1-x}N_x$ ~ 110 nm	$In_yGa_{1-y}As_{1-x}N_x$ ~ 110 nm	$In_yGa_{1-y}As_{1-x}N_x$ ~ 85 nm
buffer GaAs ~ 0.3, 0.4 µm	buffer GaAs ~ 0.3, 0.4 µm	buffer GaAs ~ 0.3 µm
n-GaAs:Si substrate 350±25 µm	n-GaAs:Si substrate 350±25 µm	n-GaAs:Si substrate 350±25 µm
T_g = 575°C, t_g = 30 min	RTA process	T_g = 585°C, t_g = 10 min

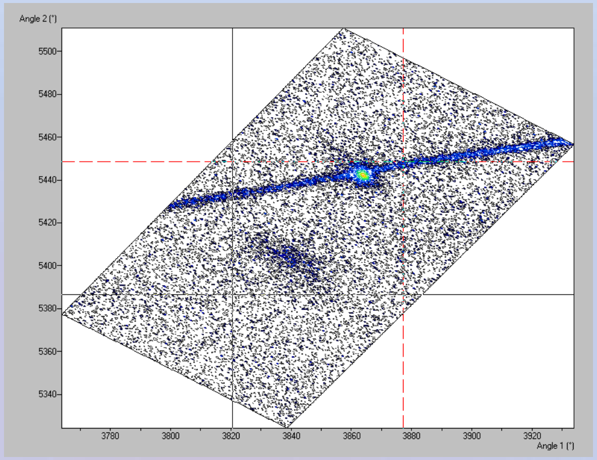
B. Ściana, et. al., Crystal Research and Technology, 47, 313 - 320 (2012)

HRXRD

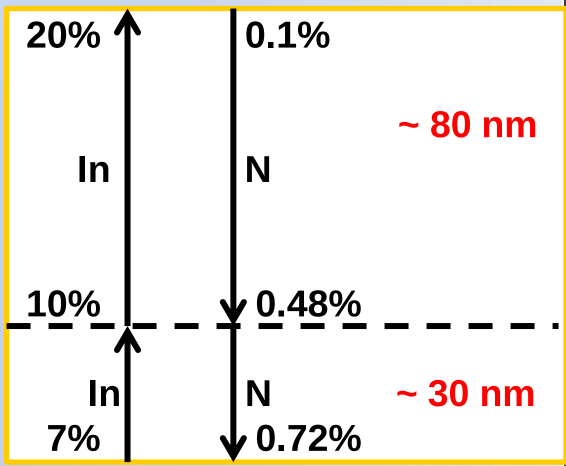
NI52n, NI52nA



Diffraction curves for the 004 reflection

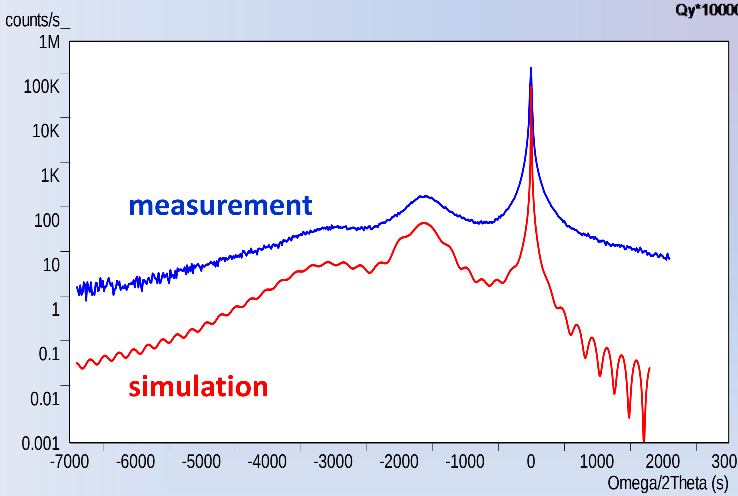


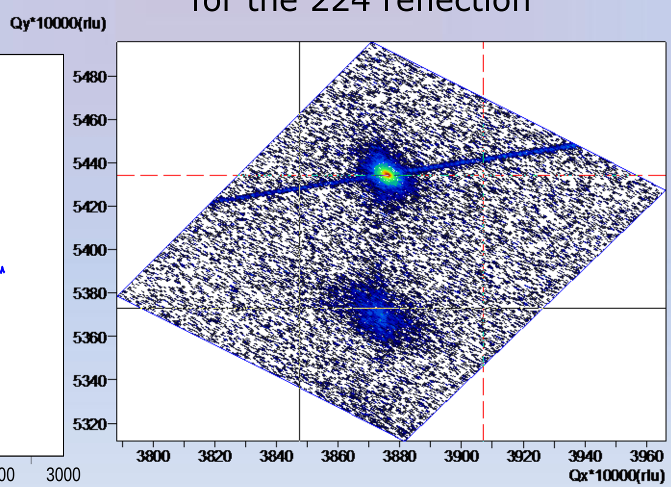
Reciprocal space maps
for the 224 reflection

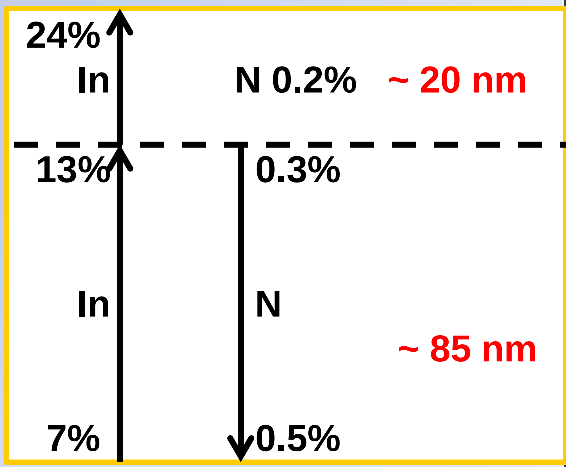


fully relaxed

NI74n



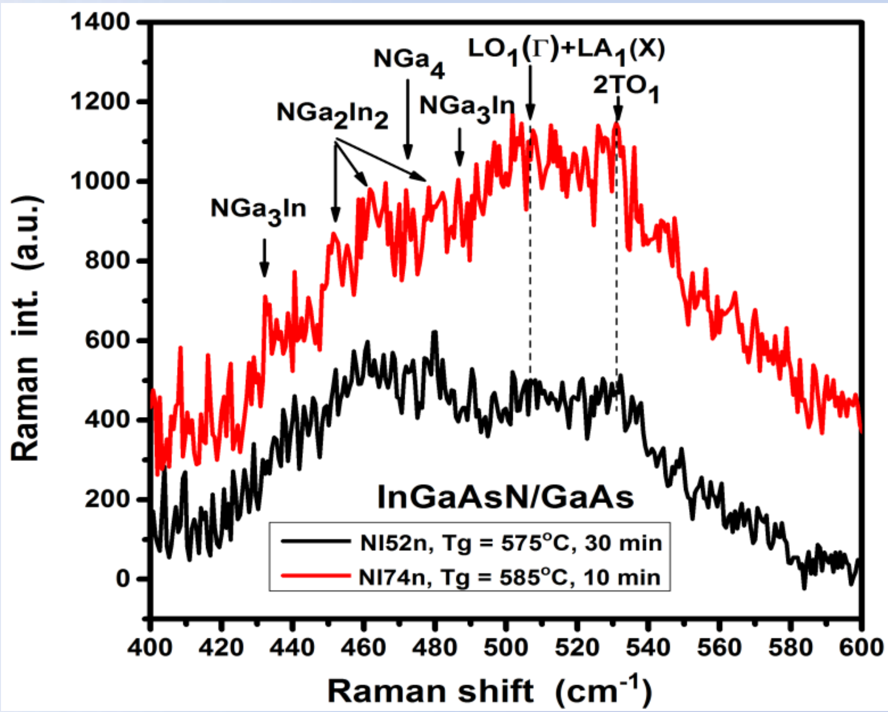




fully strained

Raman spectroscopy

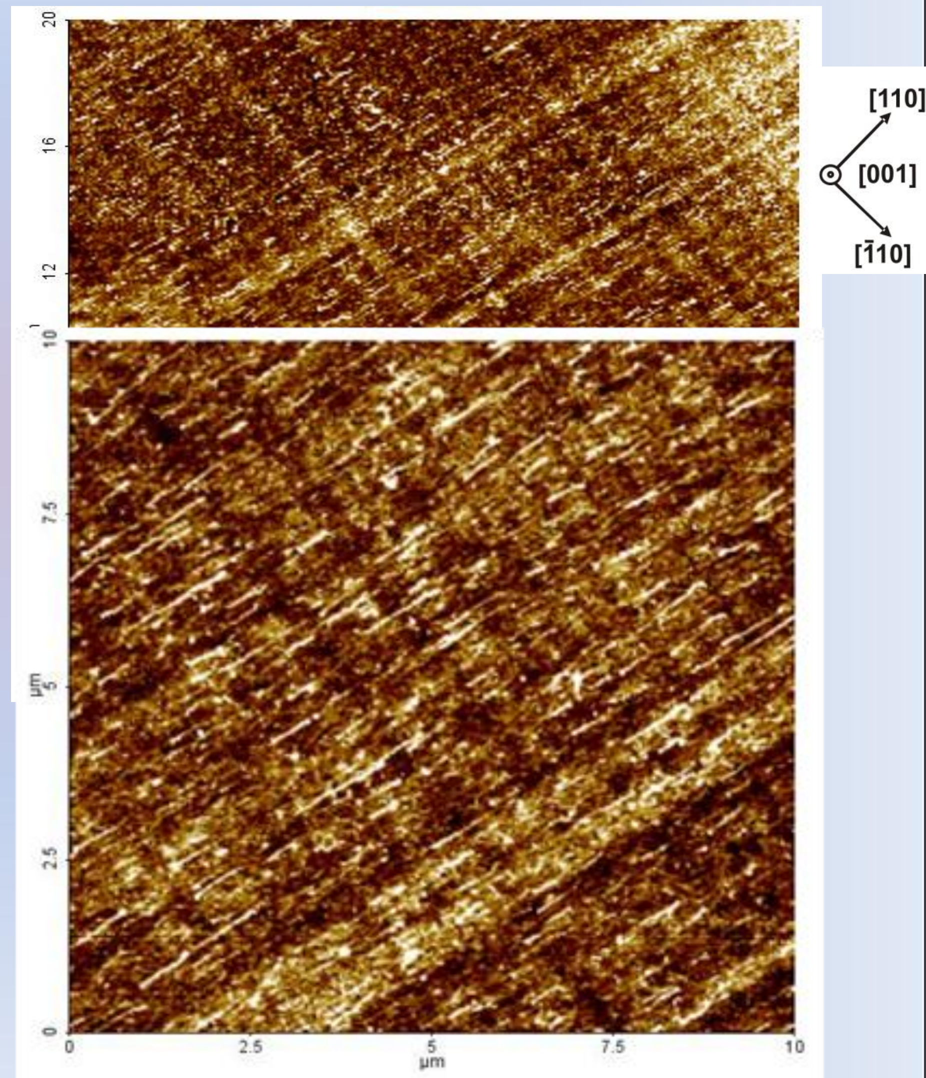
NI52n + NI74n



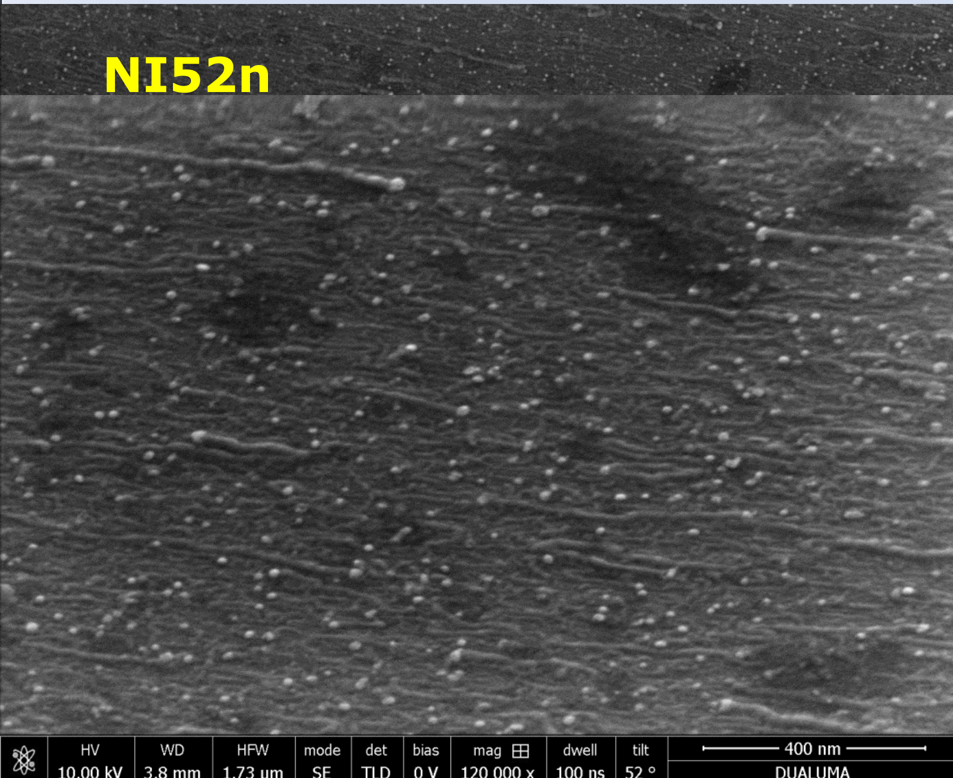
Spectral range of the N-related local vibrational modes: visible modes connected with different N atoms configurations - **NGa_3In, NGa_2In_2, NGa_4**

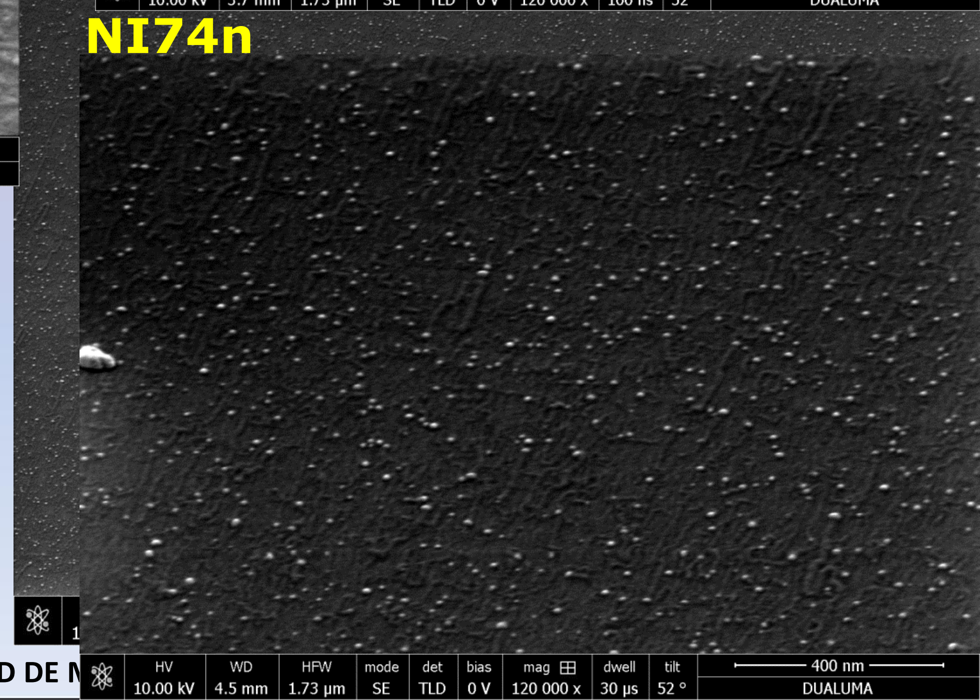
AFM

NI52n



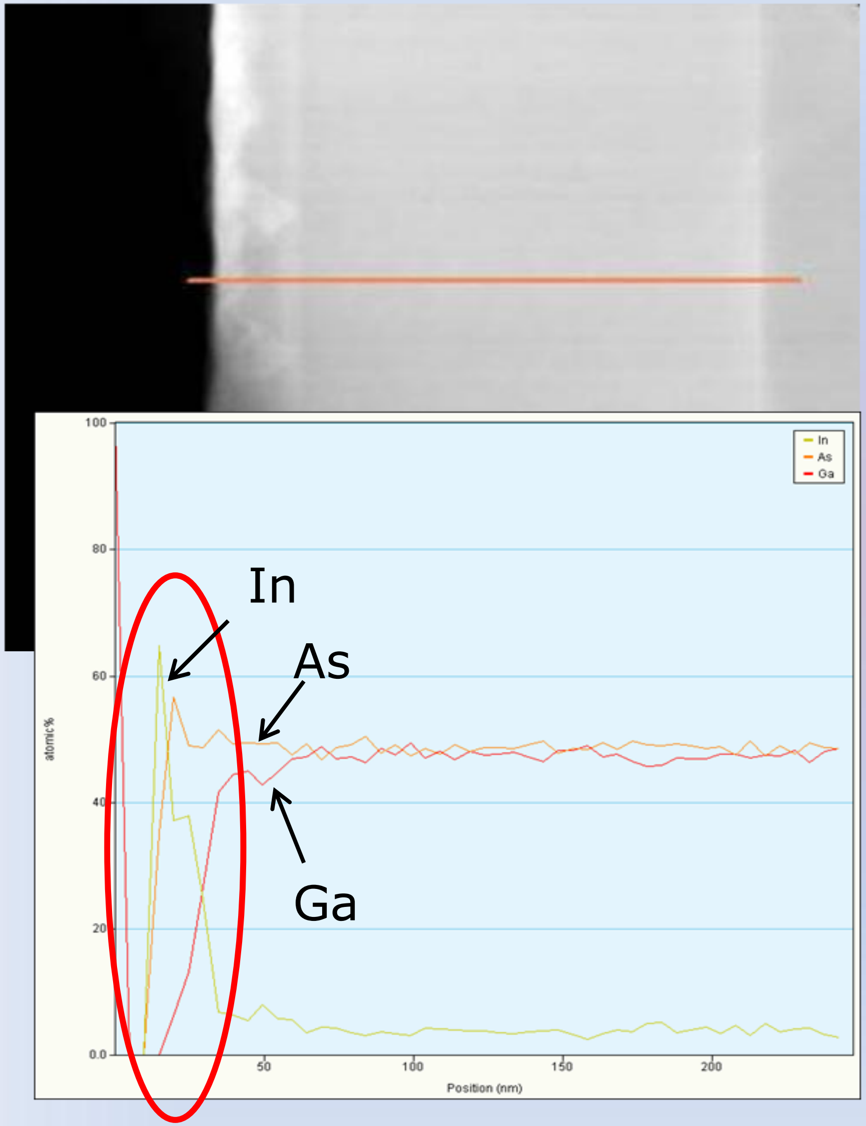
SEM

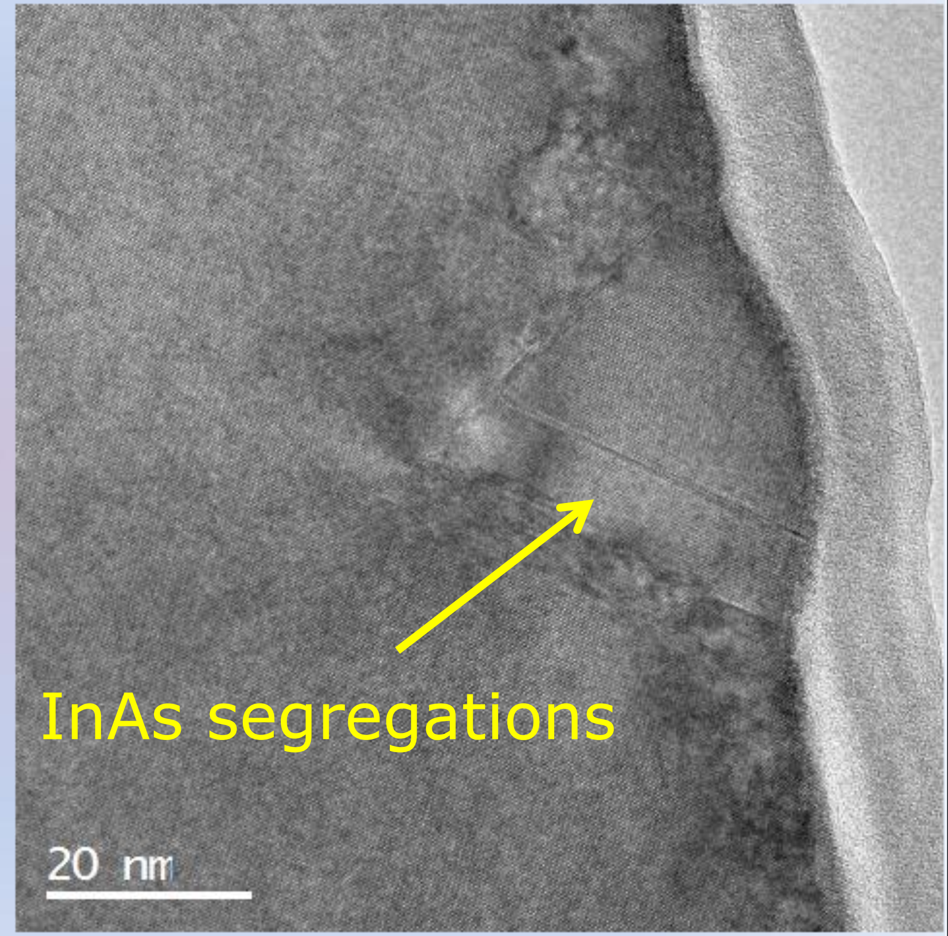




- elongated bulges on the surface of NI52n samples (smaller on NI74n)
- white nanometric spots on layer surfaces

STEM + HRTEM


In
As
Ga
atomic%
Position (nm)
100
80
60
40
20
0.0
50
100
150
200

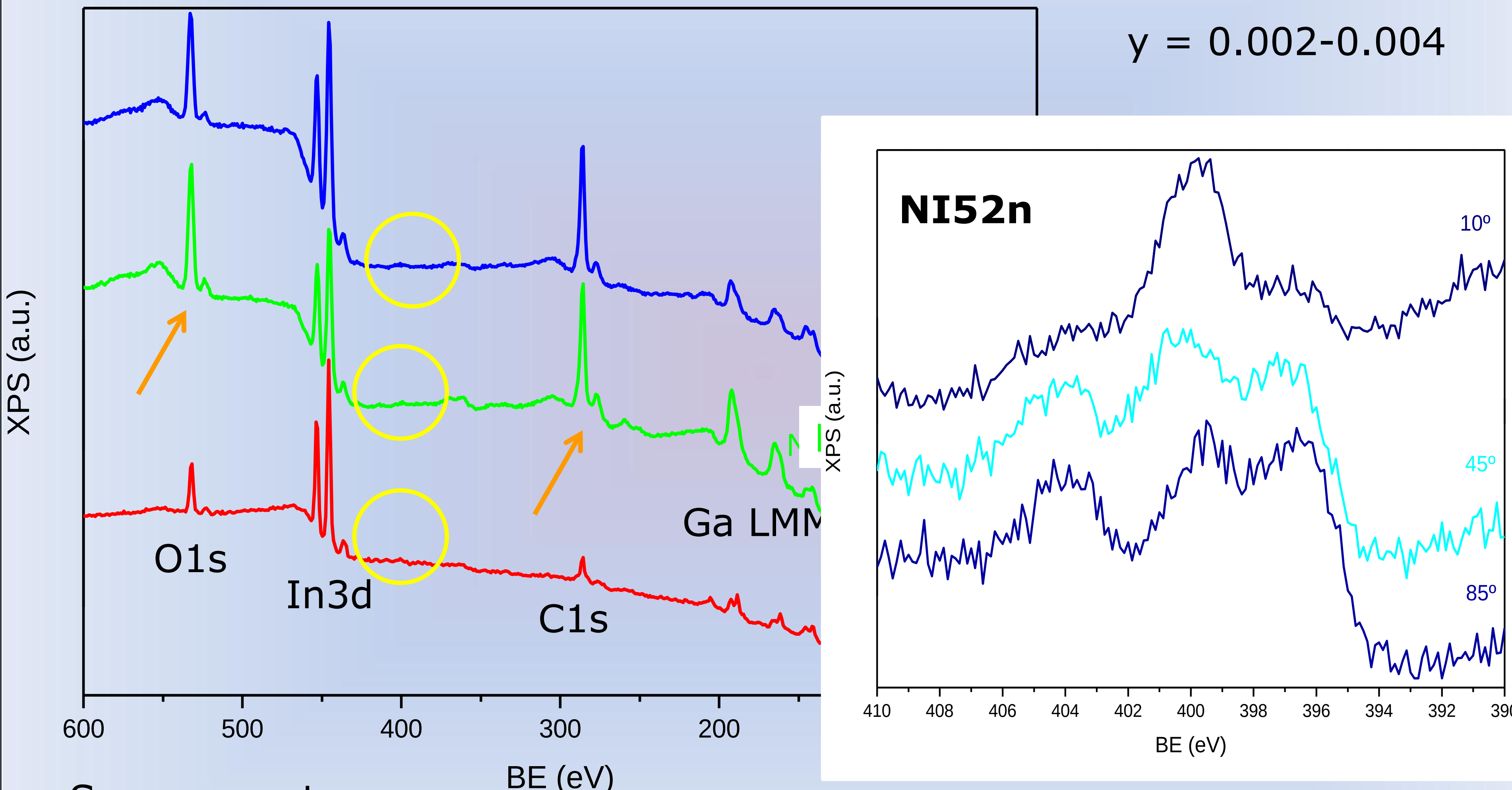

InAs segregations
20 nm

ARXPS

$In_xGa_{1-x}As_{1-y}N_y$

N content very low

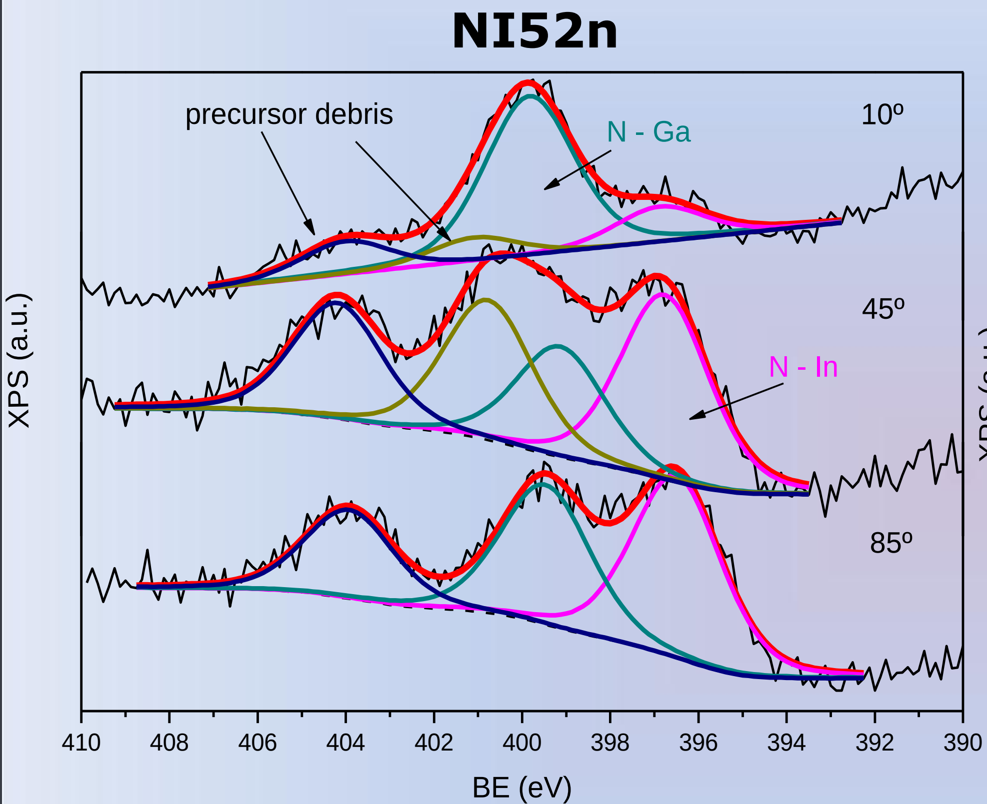
$y = 0.002\text{-}0.004$

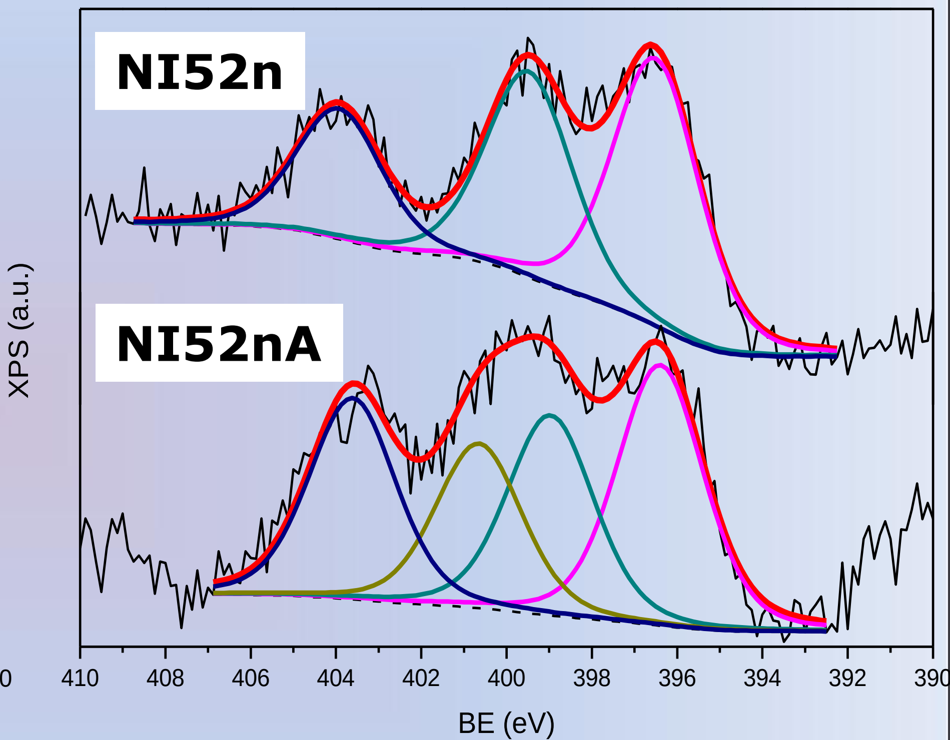


Survey spectra

ARXPS

N 1s core level spectra



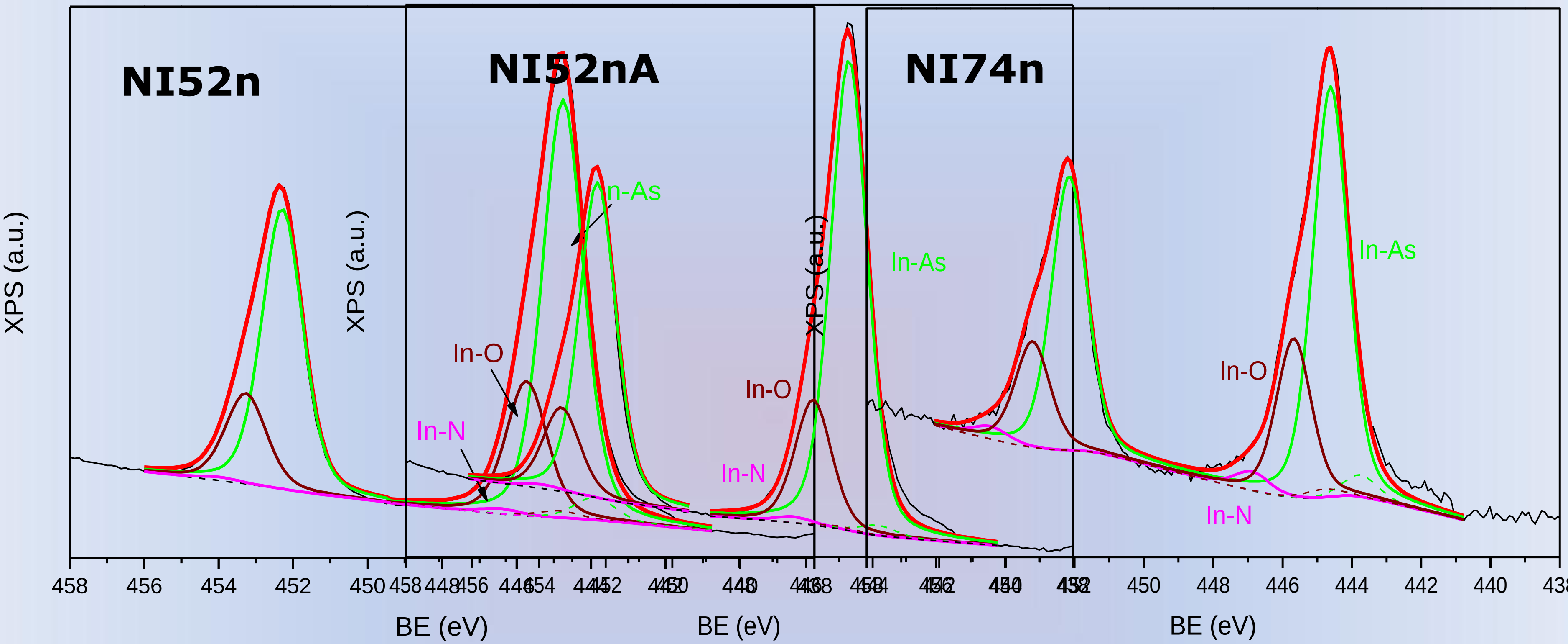


- N – Ga bonds at surface
- In content decreases as depth increases

- [N-In]/[N-Ga] increases after annealing, 1.3 ⟶ 1.5

ARXPS

In 3d core level spectra



NI52n	NI52nA	NI74n
[In-N]/[In-As] ~ 1%	[In-N]/[In-As] ~ 1.3%	[In-N]/[In-As] ~ 4.5%

Summary

• InGaAsN layers characteristics are very much dependent on growth temperature.

• Regarding the structural quality of the samples:

- no improvement has been observed after RTA,

- better structural quality achieved with high growth temperature.

• More residues and contaminants in the surface of the samples prepared at lower temperature, even after annealing.

• Layer growth at higher temperature is a better option for increasing the number of In- N bonds in the layer.

• The combination of several experimental techniques is crucial to achieve reliable conclusions.

Acknowledgments

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