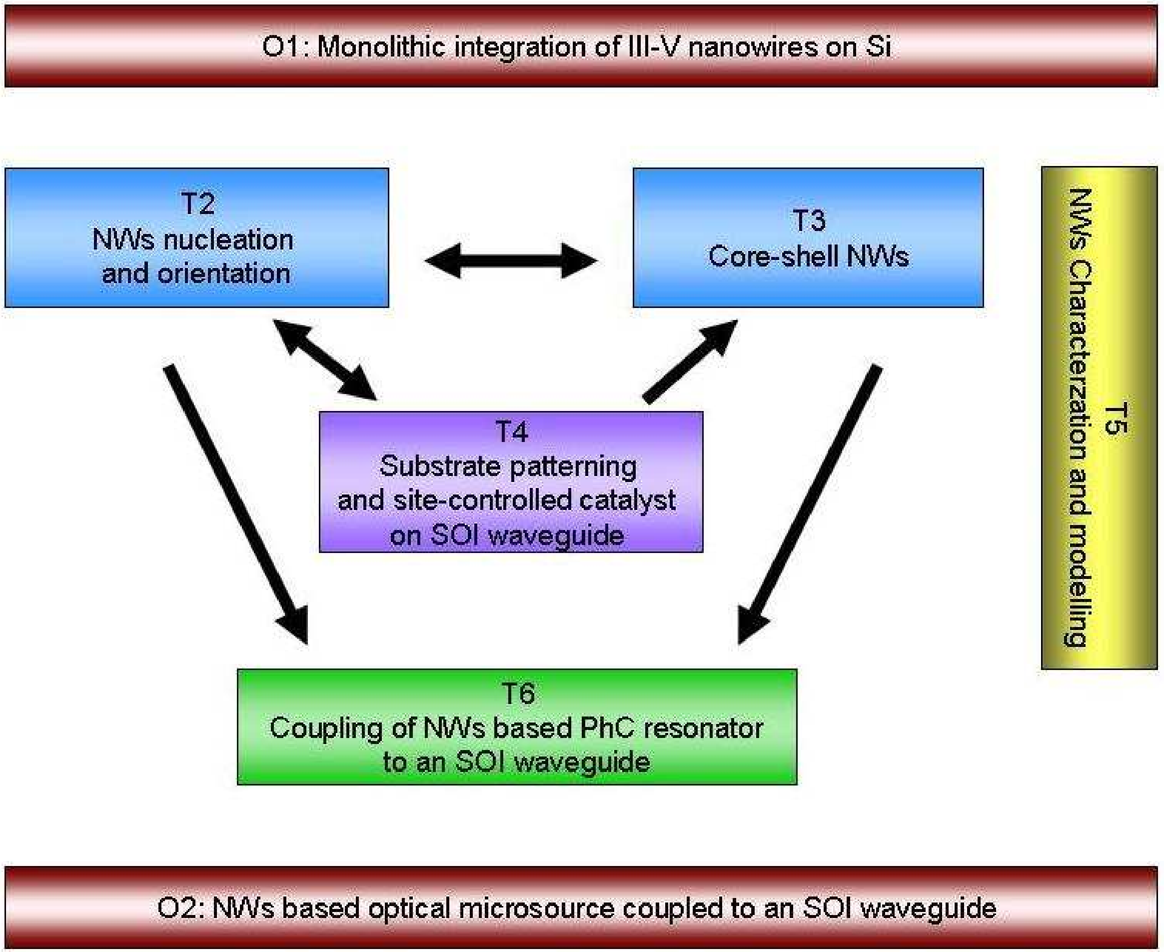
Volet scientifique: Répartition des tâches



T2: INL (M. Gendry)

T3: LPN (JC. Harmand)

T4: LTM (B. Salem)

T5: Foton (JM. Jancu)

T6: CEA (B. Ben Bakir)

Task 2: NWs nucleation and orientation

- **T2.1: Alternative to Au-catalyst (INL, LTM)**
  The person in charge of T2.1 will be H. Dumont from INL.

  ☞ To avoid Au contamination in silicon process lines using alternative catalyst or self-catalyzed growth

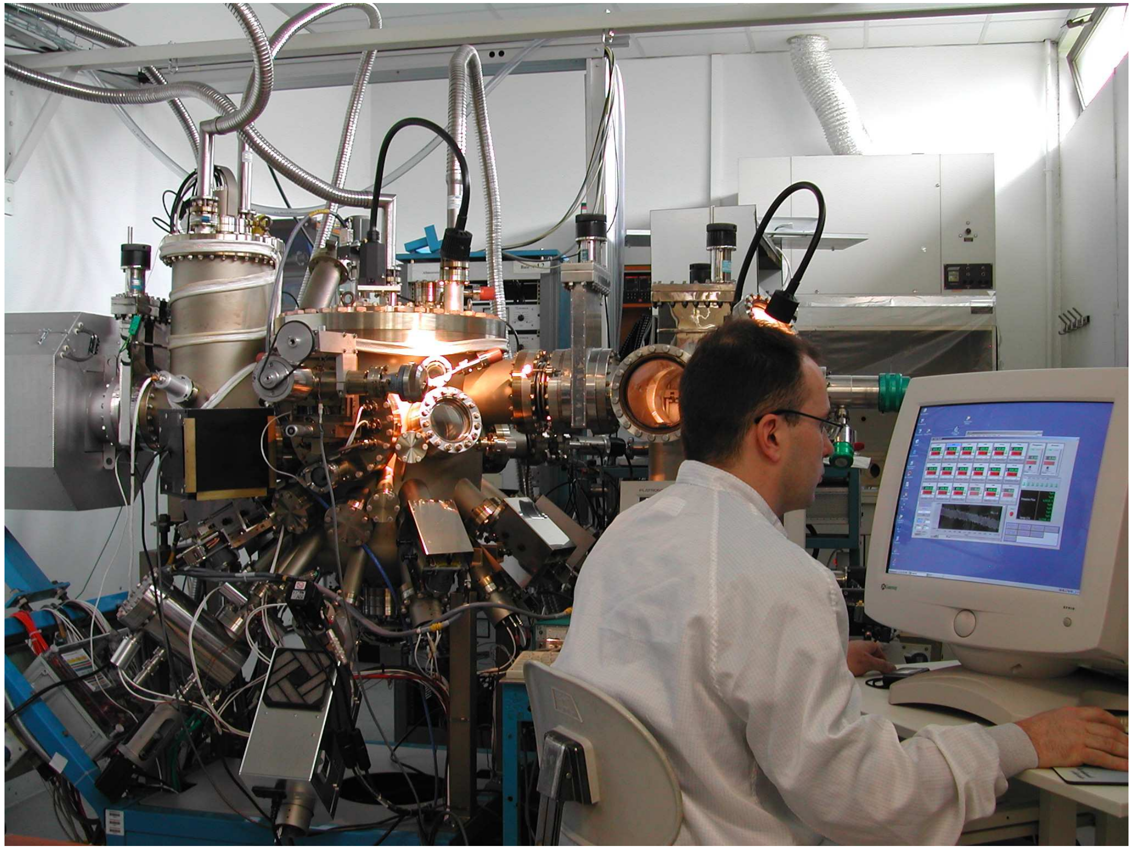
- **T2.2: Vertically standing NWs on Si(001) (INL)**
  The person in charge of T2.2 will be G. Saint-Girons from INL.

  ☞ To promote vertically-standing NWs on Si(001) orientation with the use of a thin oxide ($SrTiO_3$) template layer

☞ To avoid the formation a 2D layer between the NWs by appropriate growth conditions and substrate masking

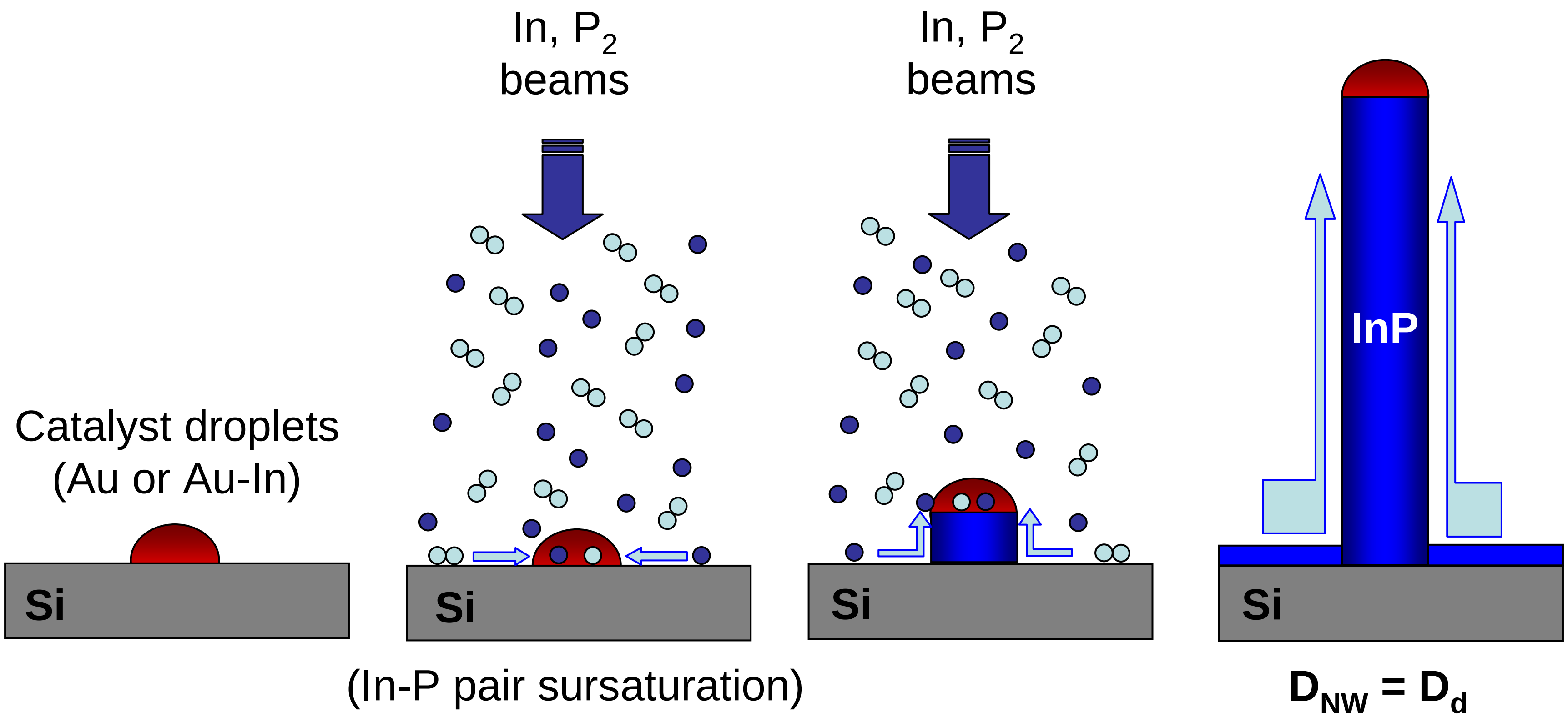
Acquis INL: croissance VLS-MBE de NWs III-V/Si

Thèse de K. Naji, 2007-2010, Stages CMCU de H. Khmissi (U. Monastir) en 2010 et 2011



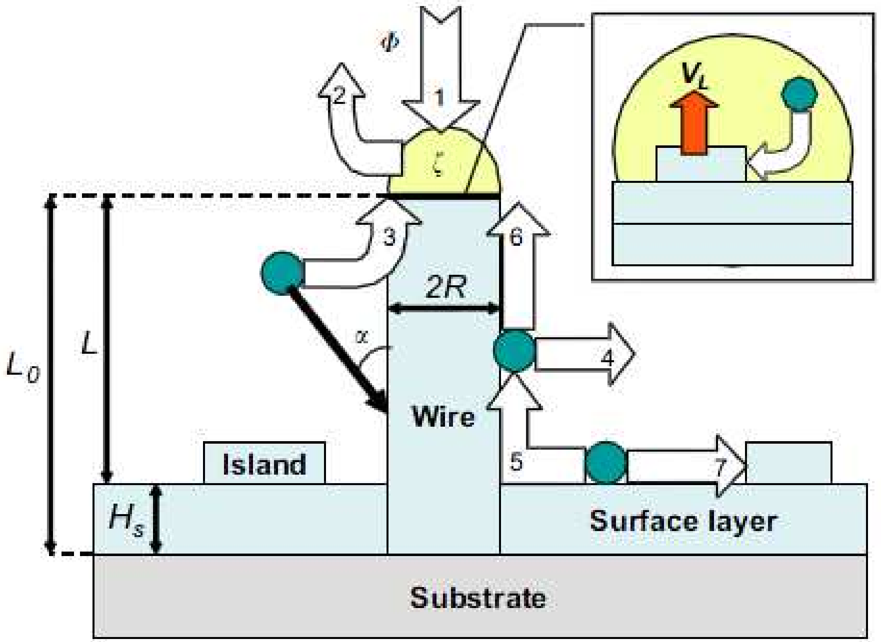
VLS-MBE growth

T_G , P_{In} , P_{P2}



VLS-MBE growth mechanisms

Modèles de V. Dubrovskii et al, 2004-2005, + JC Harmand, 2006
Modèles de V. Dubrovskii et al + JC Harmand, 2006
F. Glas, J. C. Harmand, and G. Patriarche, Phys. Rev. Lett. 99, 146101 (2007)
V. Dubrovskii, N. V. Sibirev, J. C. Harmand and F. Glas, Phys Rev B, 78 , 235301 (2008)



VLS-MBE:

La sursaturation de la goutte en paires III-V est induite par la diffusion de surface des adatomes

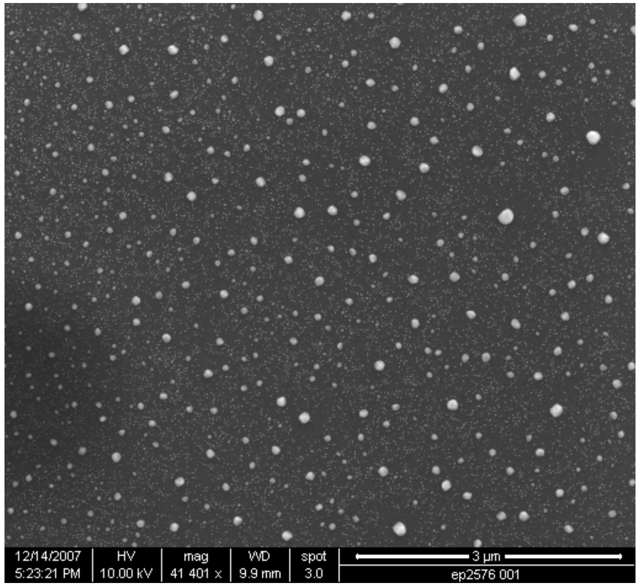
« Diffusion-induced growth »

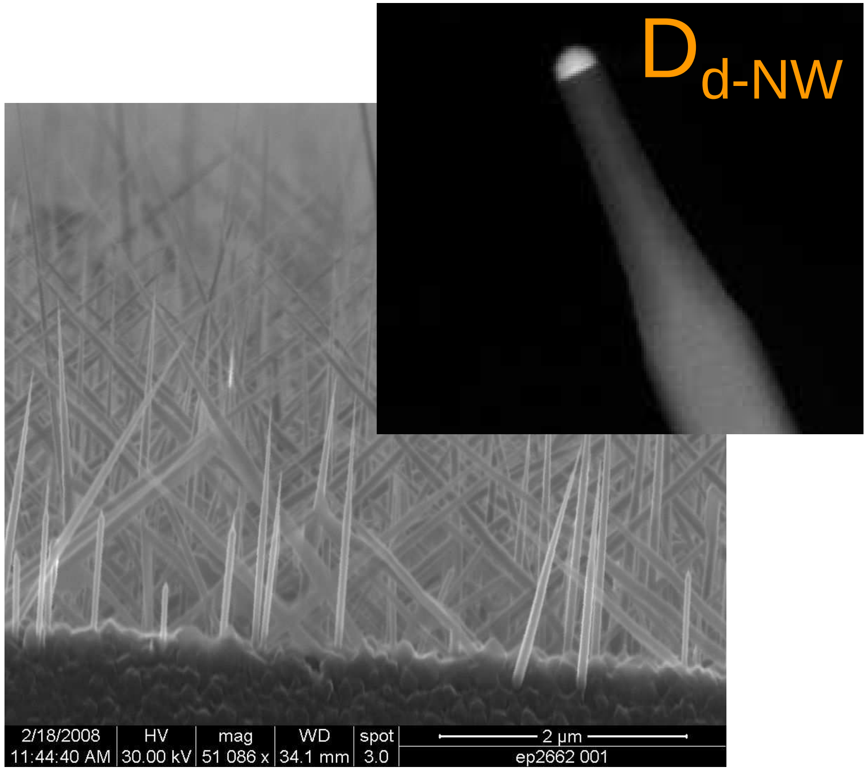
III-V NWs / Si growth: specificity (1)

Critical NW diameter D_C due to lattice mismatch

D_d : 5-60 nm
10^{11} cm^{-2}

$D_{d\text{-}NW}$ < 33 nm
10^{9} NWs/cm^{-2}



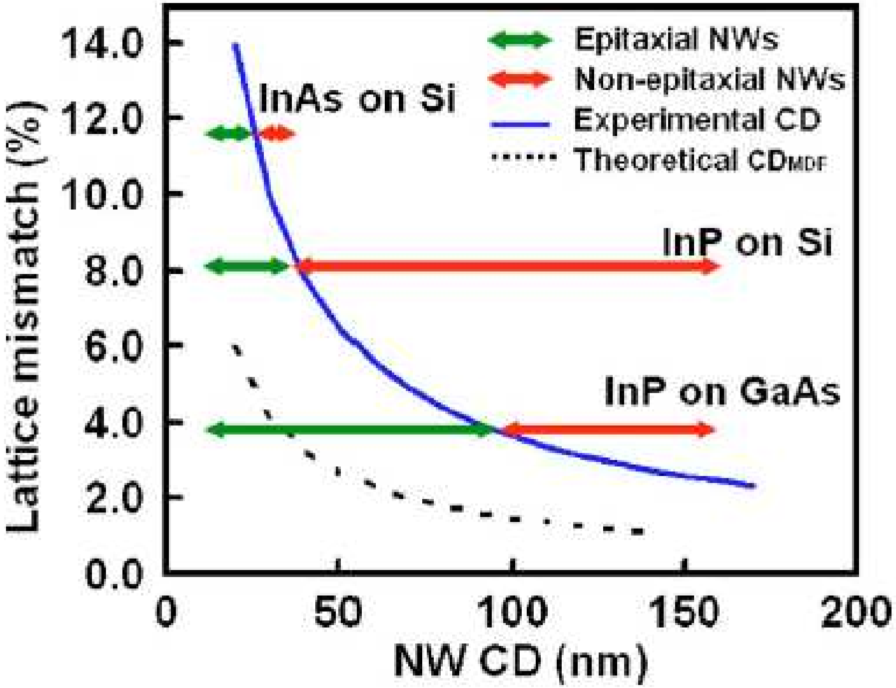


III-V NWs / Si growth: specificity (1)

Critical NW diameter D_C due to lattice mismatch

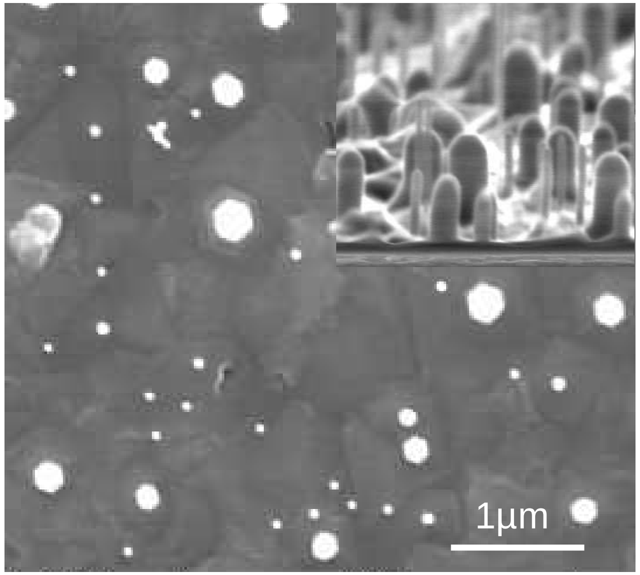
LP-MOCVD

D_C = 36 nm



InP NWs / InP(111)

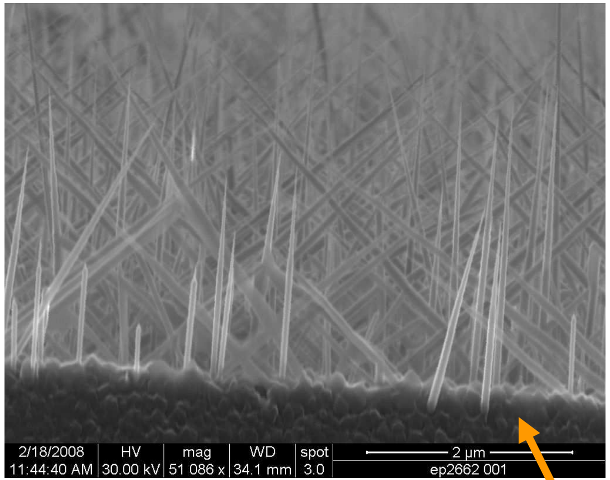
$D_{d\text{-}NW}$ = 10 – 200 nm



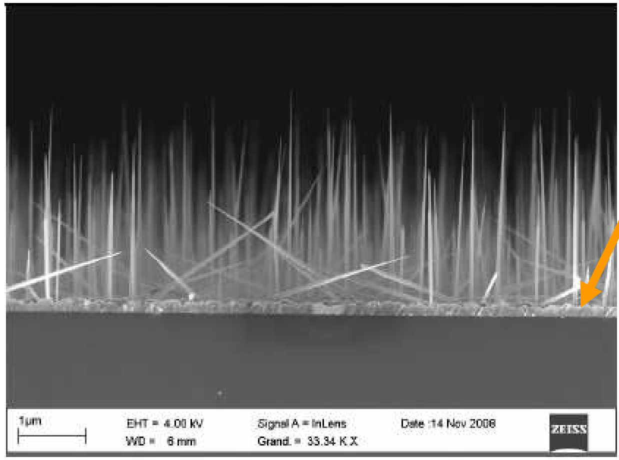
L. C. Chuang et al, Appl. Phys. Lett., 90, 043115 (2007)
E. Ertekin et al, J. Appl. Phys., 97, 114325 (2005)

III-V NWs / Si growth: specificity (2)

InP NWs /Si(001)



InP NWs /Si(111)

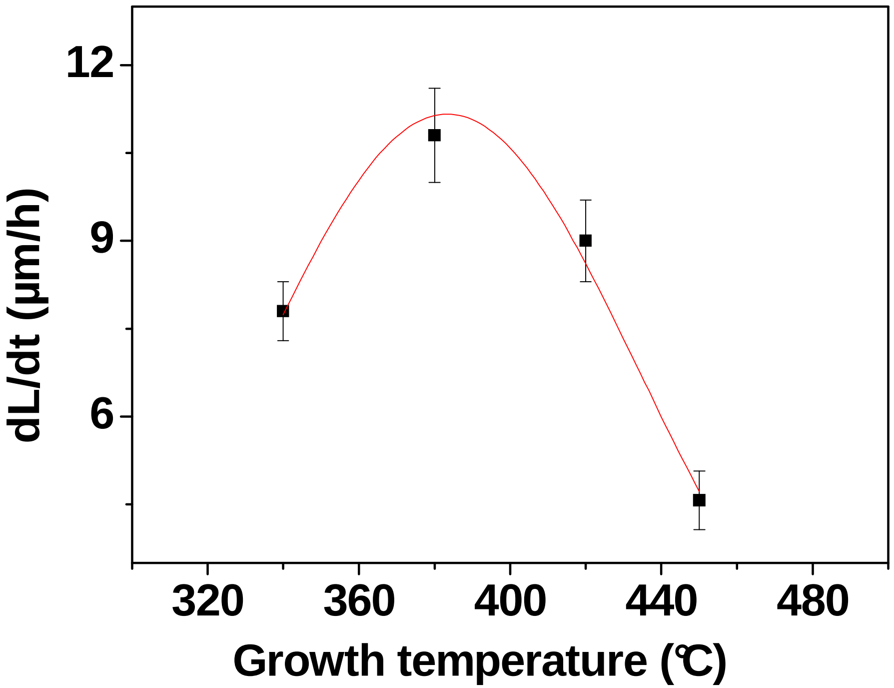


Rough InP 2D layer
e ~ 100 nm

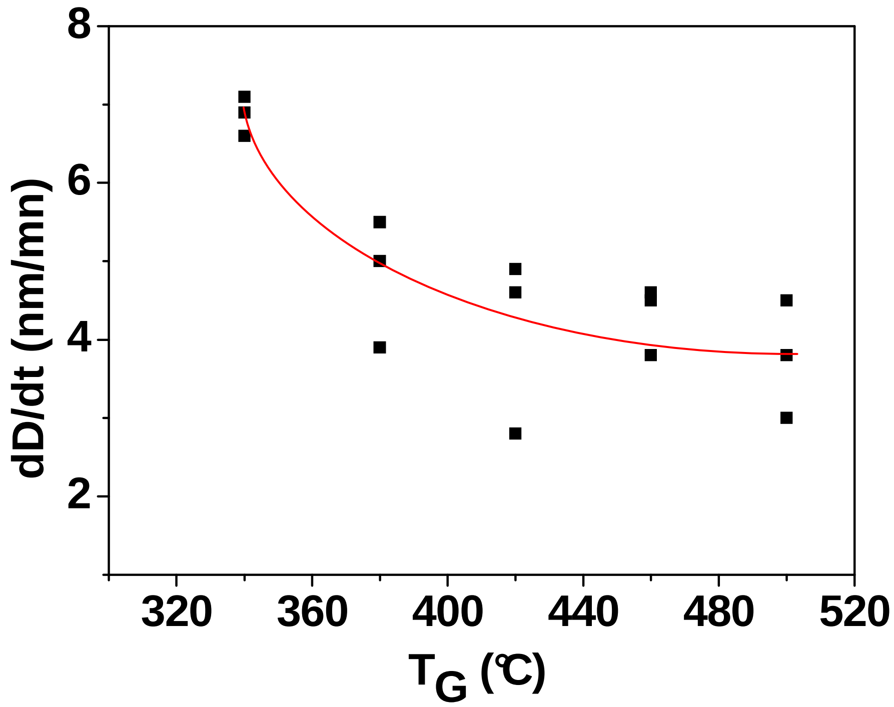
SEM images

Axial and radial growth rates

Axial growth rate

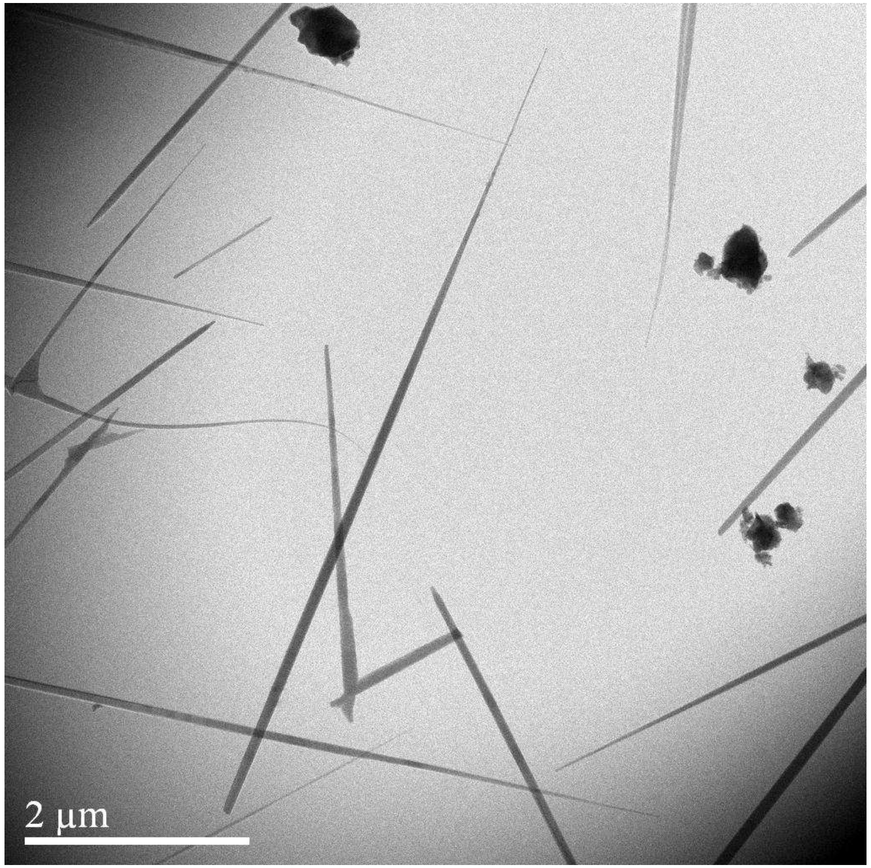


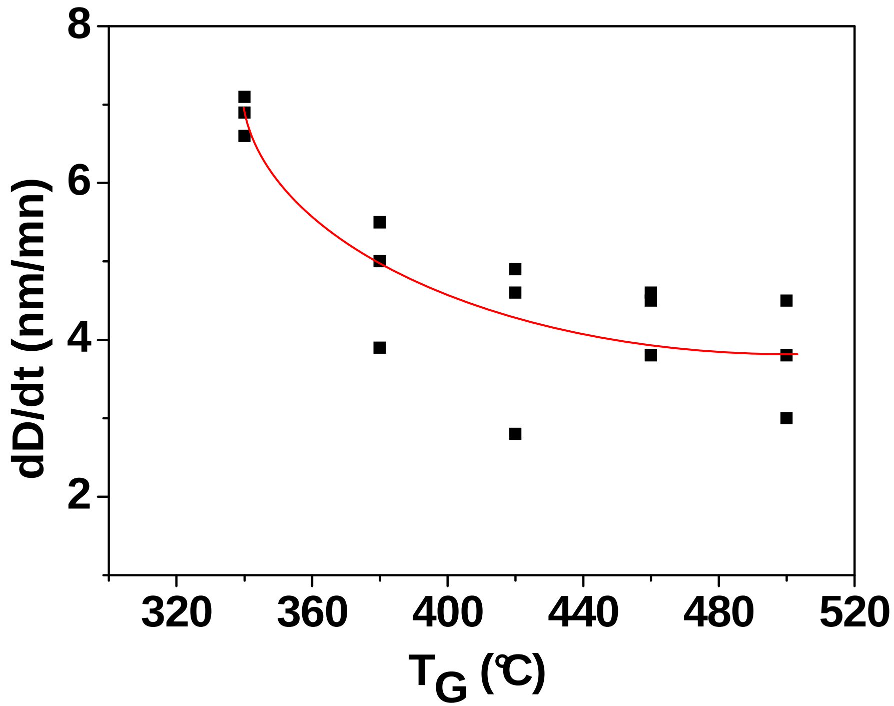
Radial growth rate



Tapered NWs: specificity (3)

Strong tapering effect





InAs/InP NWs / Si

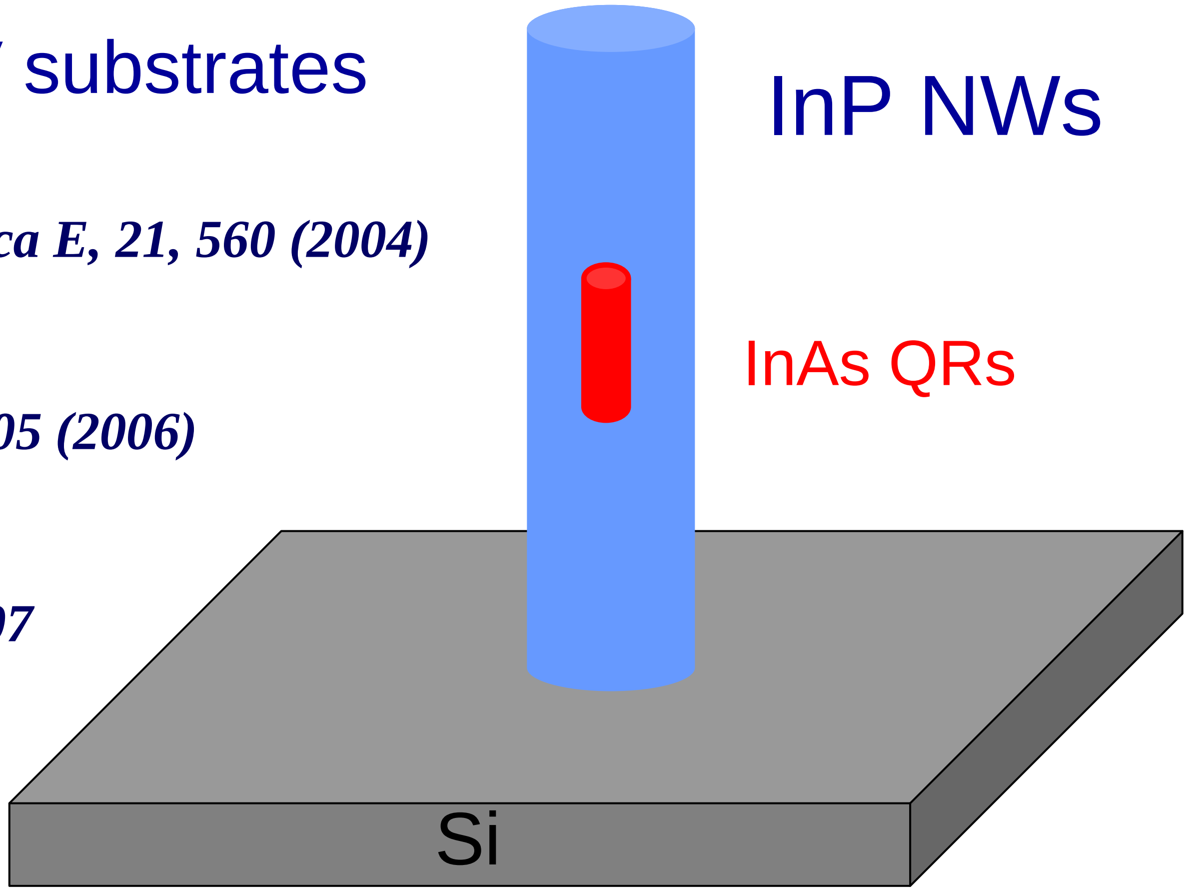
InAs QRods / InP NWs on Si

As done on III-V substrates

L. Samuelson et al, Physisca E, 21, 560 (2004)

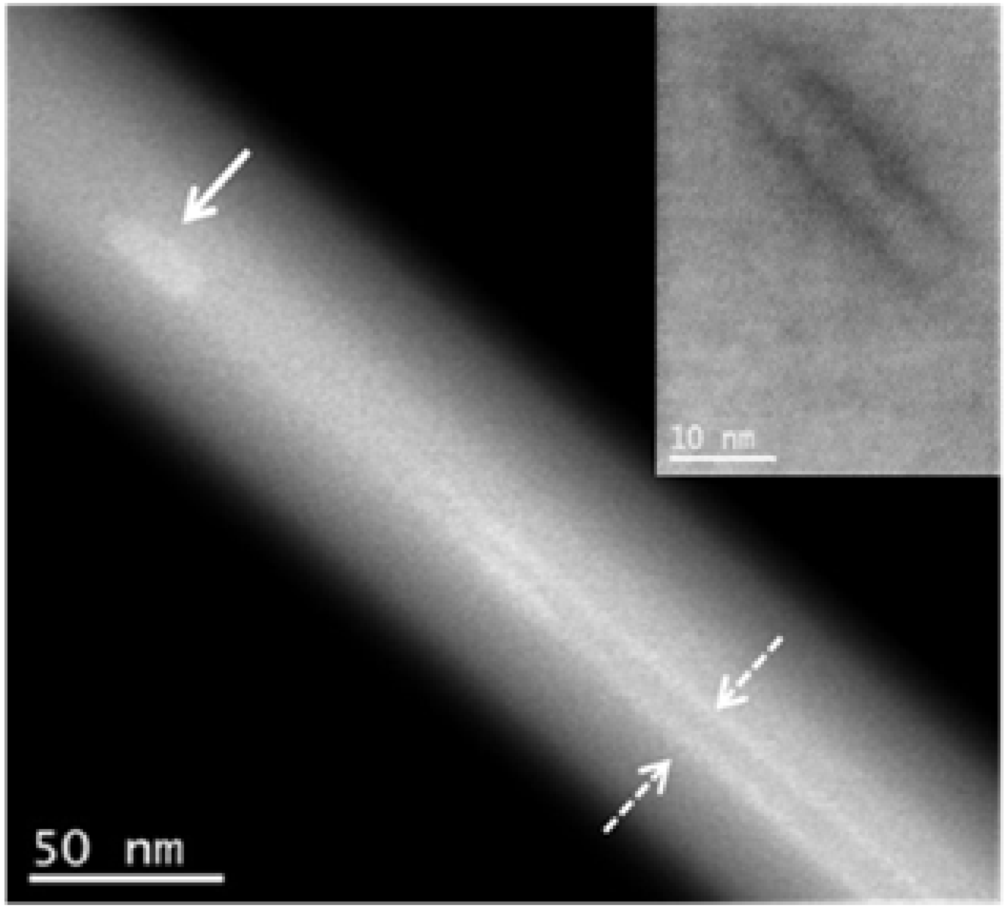
P. Mohan et al,
Appl. Phys. Lett., 88, 133105 (2006)

J.C. Harmand et al,
Images de la physique, 2007



InAs/InP NWs / Si

For 10 s InAs growth



QRs

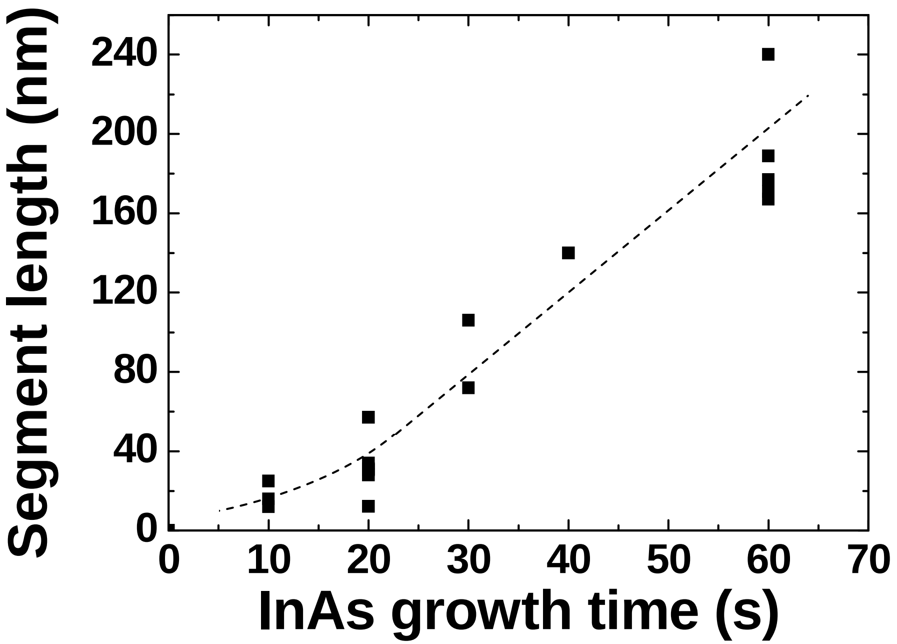
+

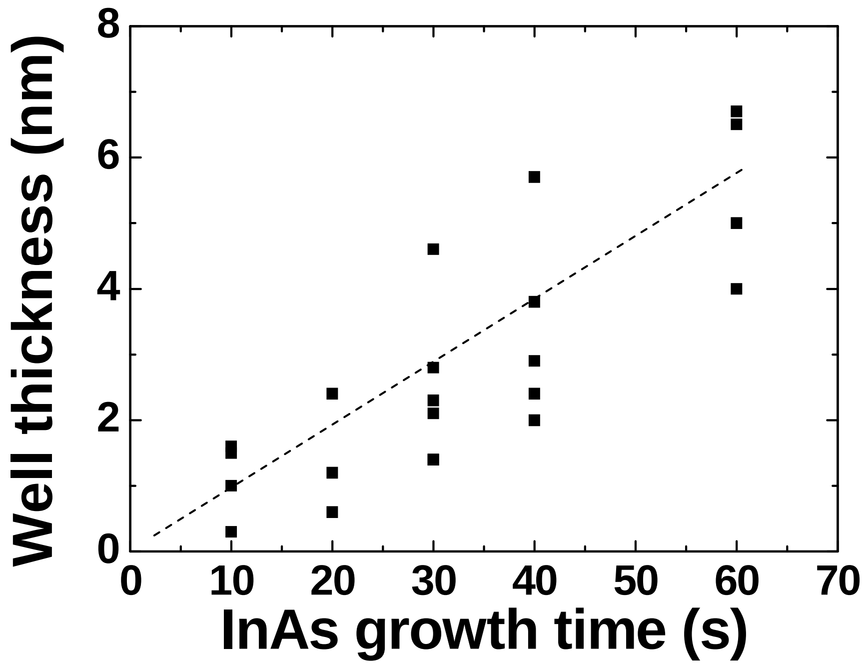
Radial QW (rQW)

InAs/InP NWs / Si

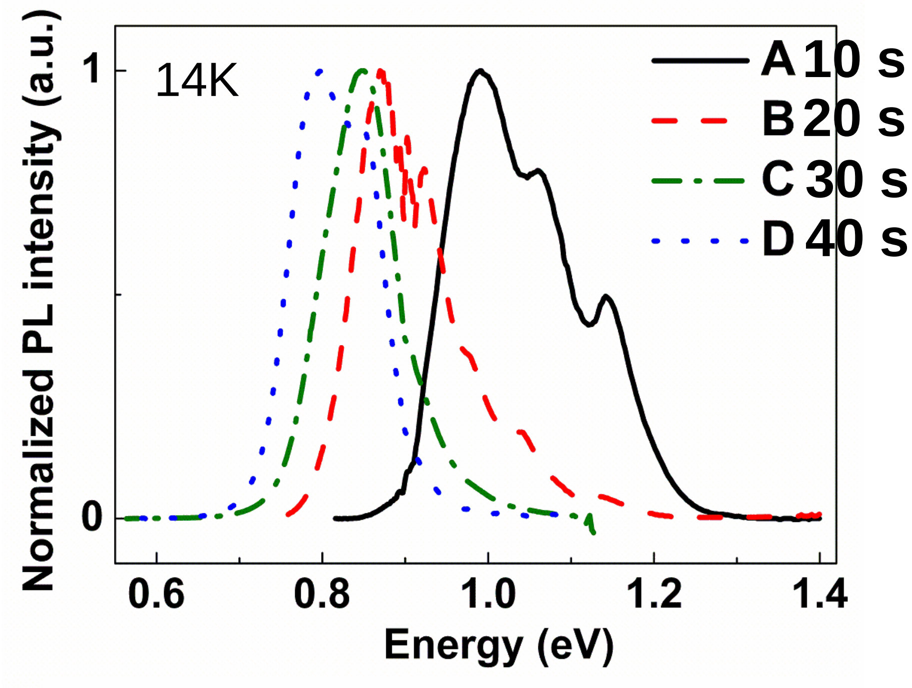
InAs growth time (10 to 60 s)

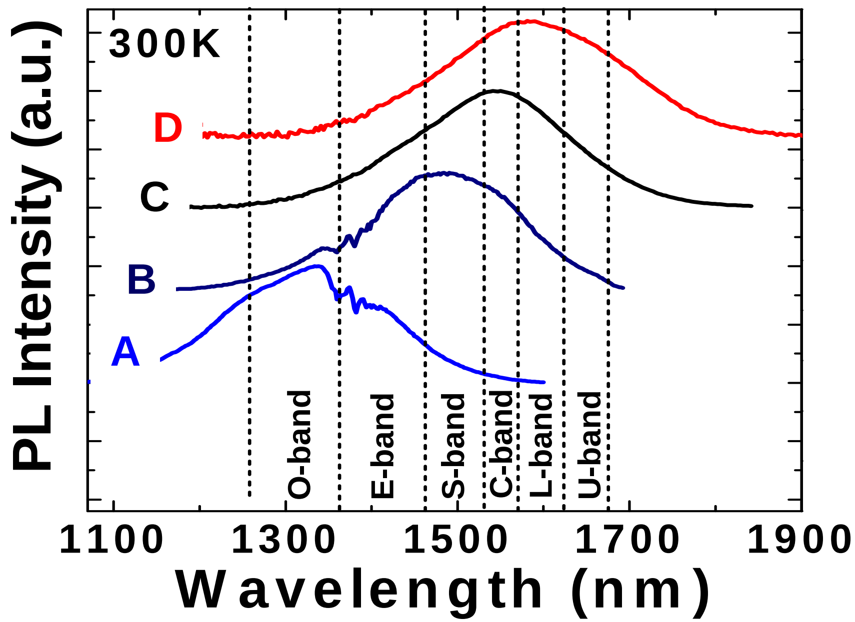
D_d = 7-12 nm





Optical properties

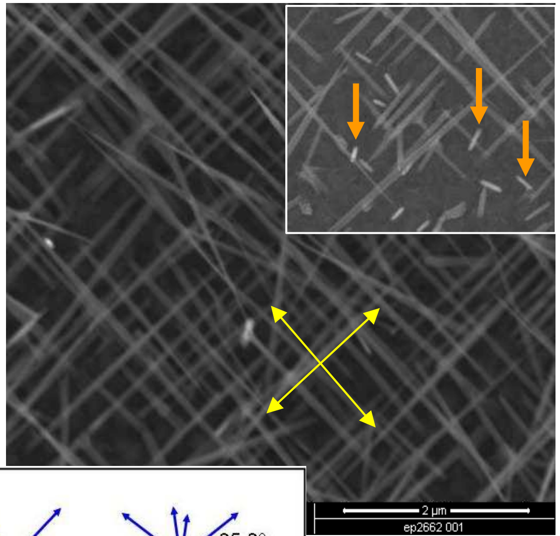


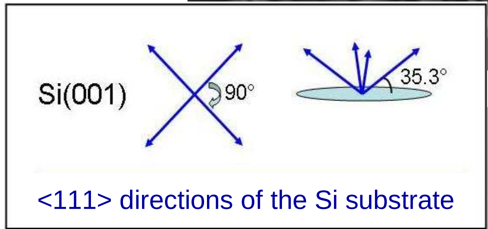


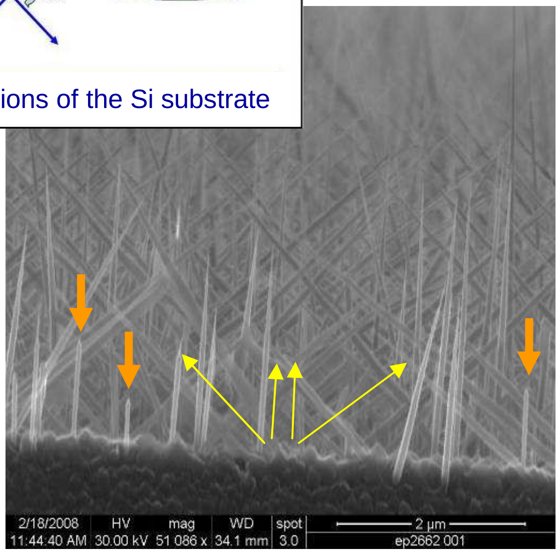
→ Emission due to the rQWs

M.H. Hadj Alouane et al, Nanotechnol., 22, 405702 (2011)

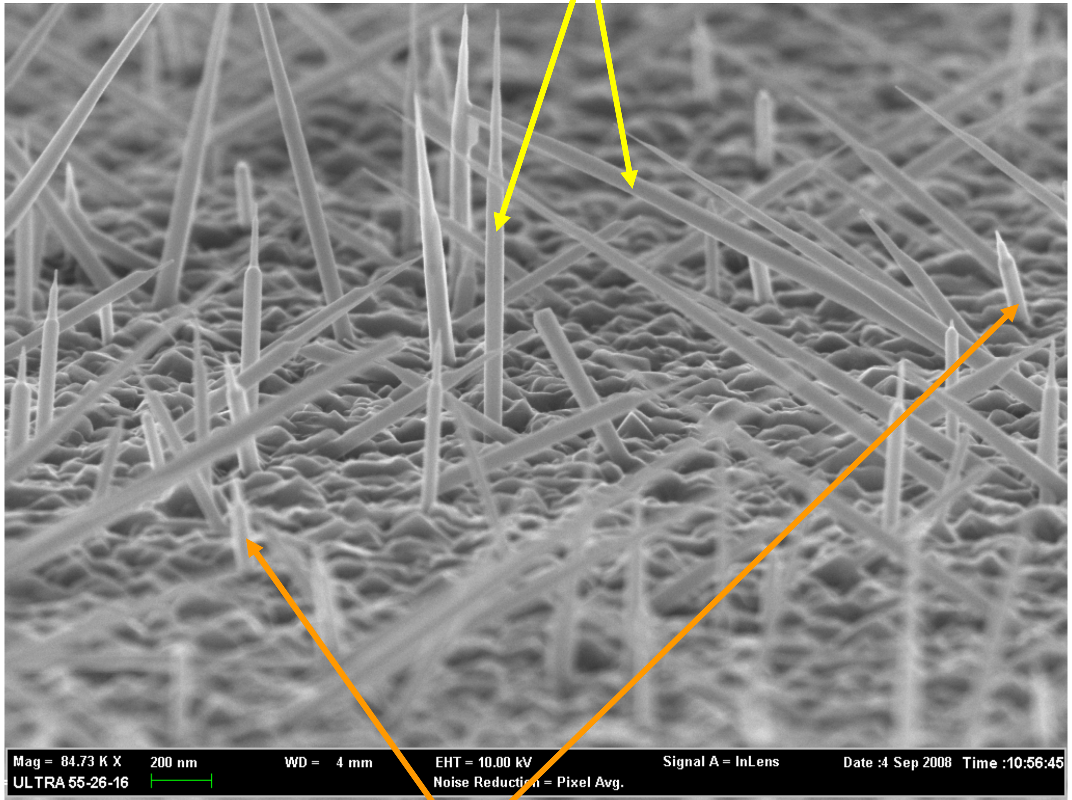
InP NWs on Si(001)







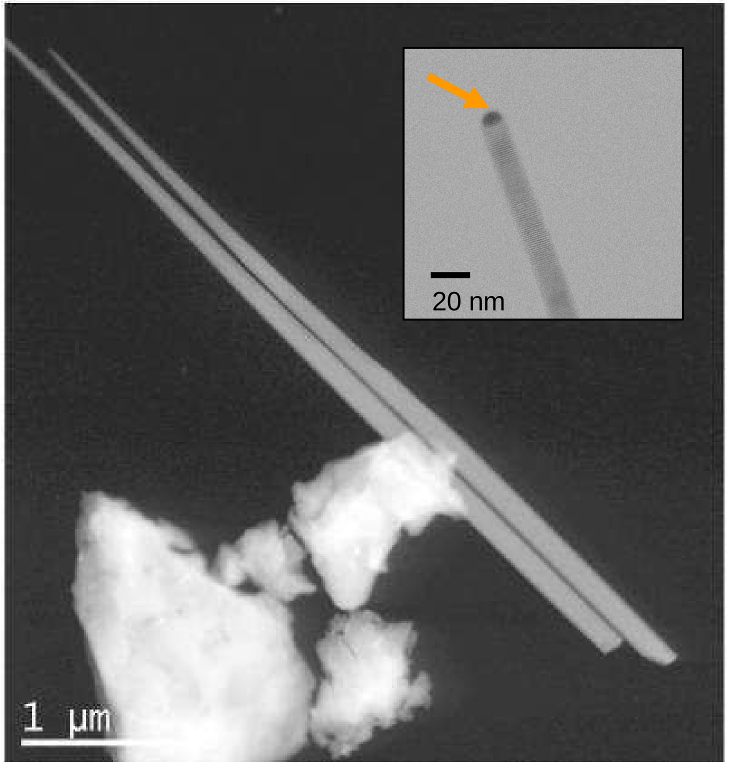
Long NWs with Si <111> directions



Short NWs less inclined

InP NWs on Si(001)

Needle like



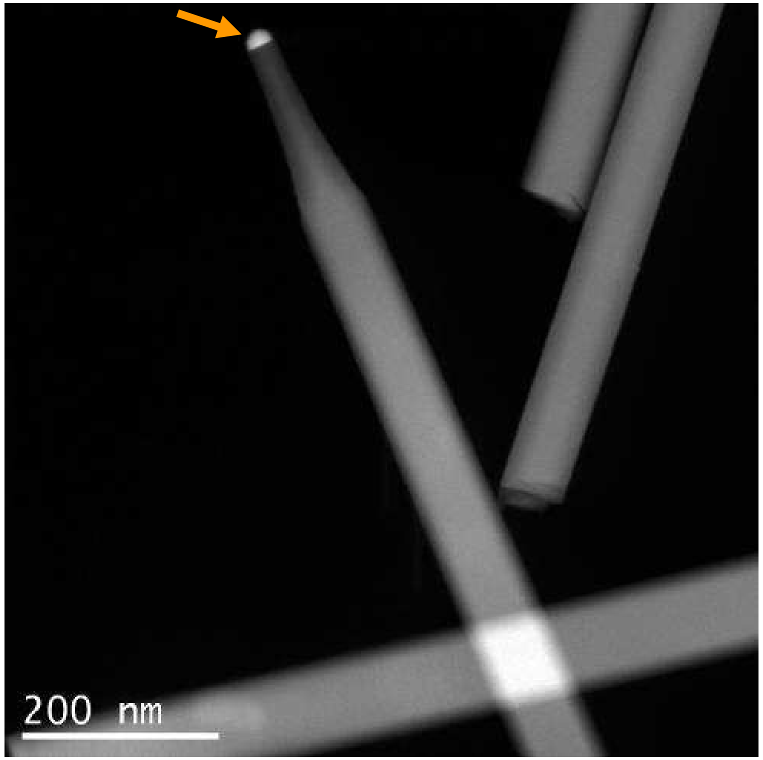
D_d < 15 nm

Axial V_G = 150-200 nm/mn

Radial V_G = 6 nm/mn

R ~ 30

Pencil like



D_d > 15 nm (< 33 nm)

Axial V_G = 50 nm/mn

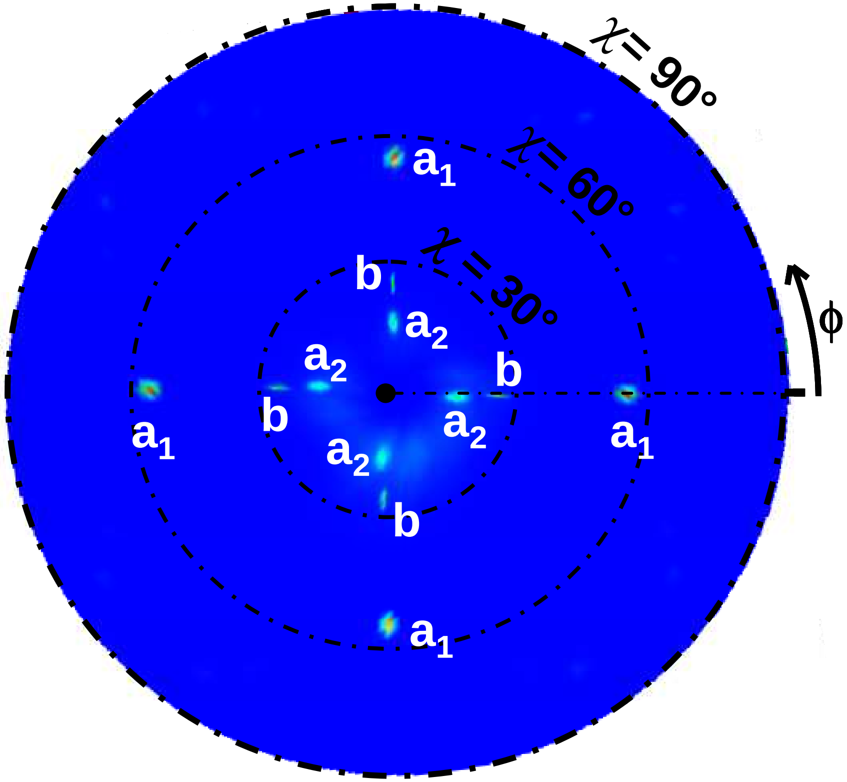
Radial V_G = 4 nm/mn

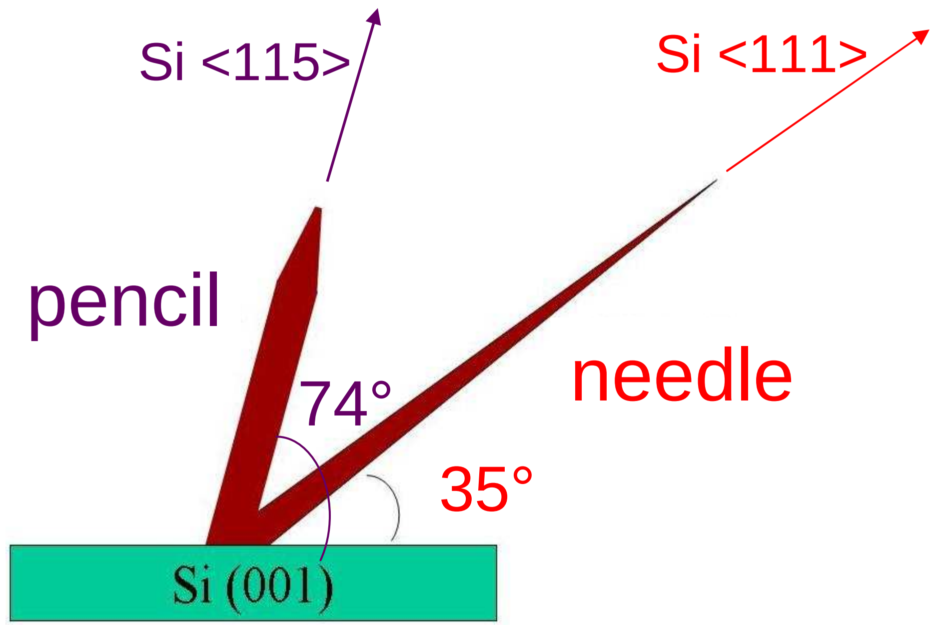
R ~ 12

InP NWs on Si(001)

X-Ray pole figure

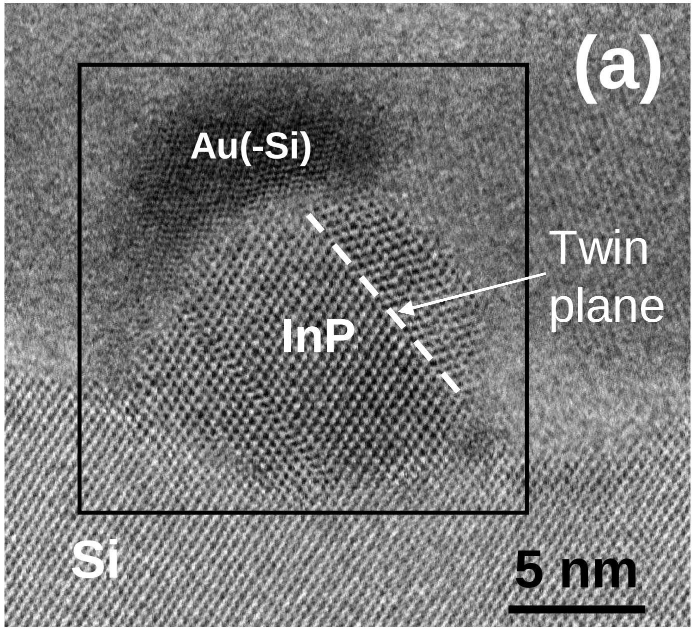
InP 0004 2Θ = 54,08°

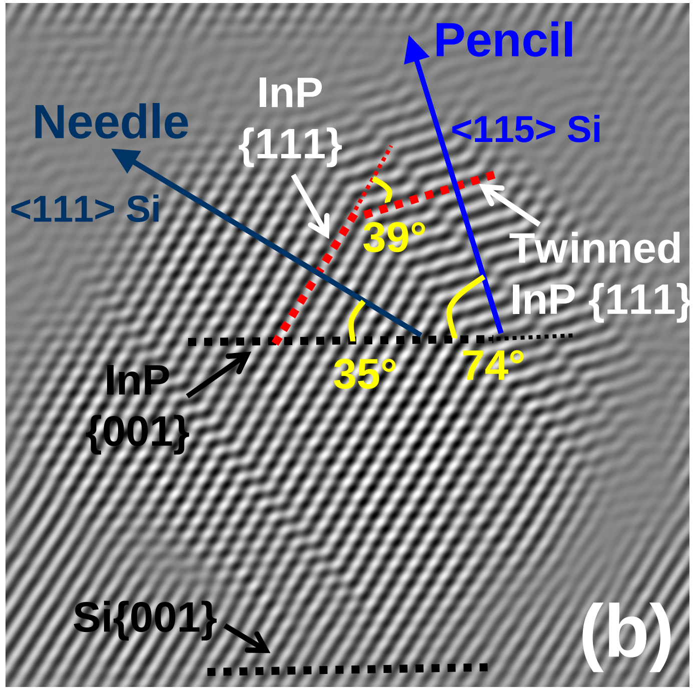




Rigaku with rotating anode

InP NWs on Si(001)

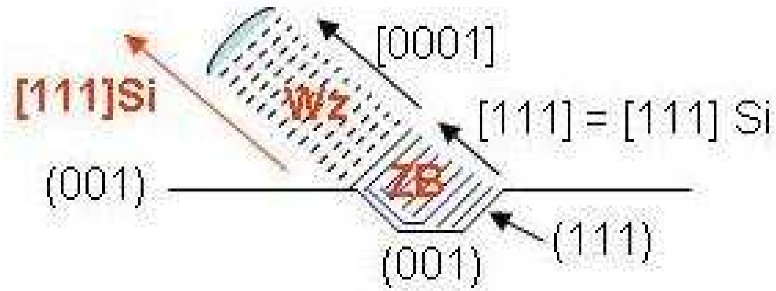




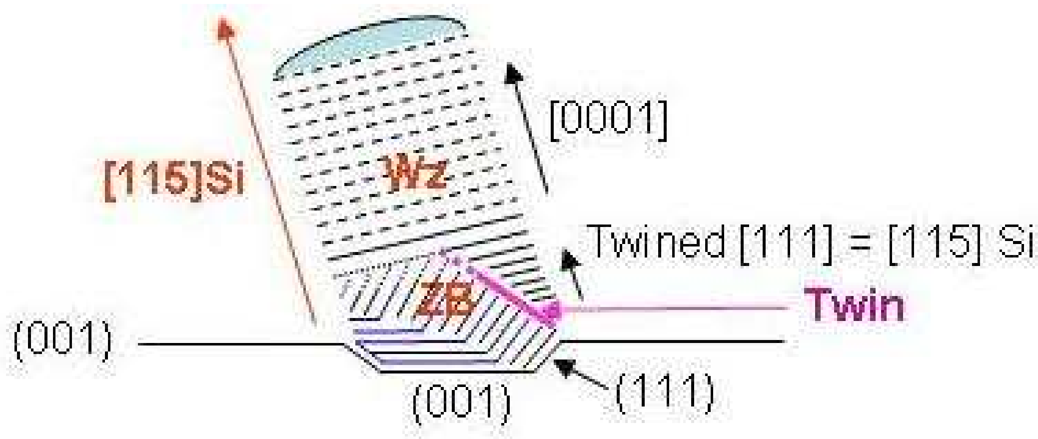
K. Naji et al, to be submitted

E. Uccelli et al, Nanoletters, 2011

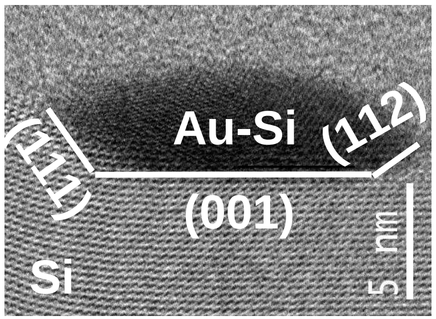
InP NWs on Si(001)

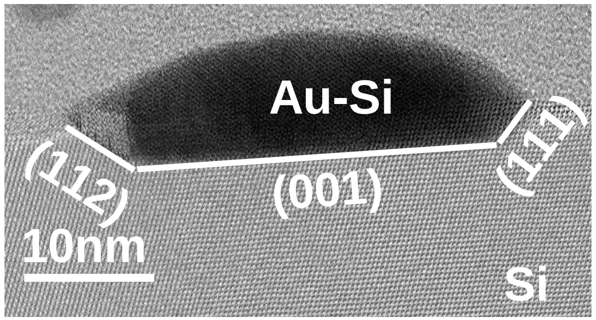


$D_d < 15$ nm

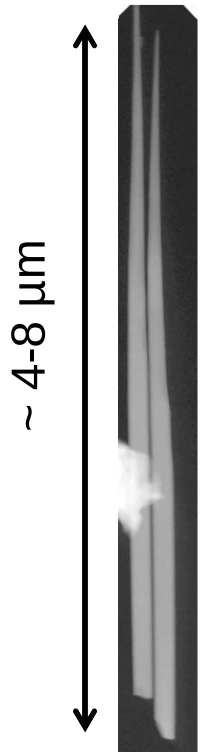


$D_d > 15$ nm





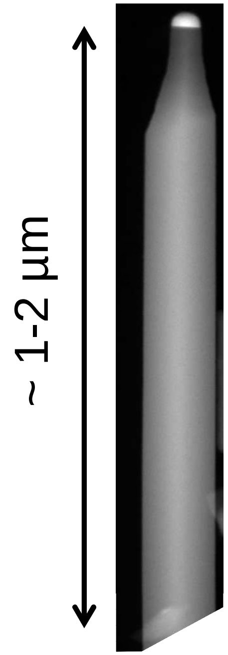
InP NWs on Si(001)



(a)

Needle

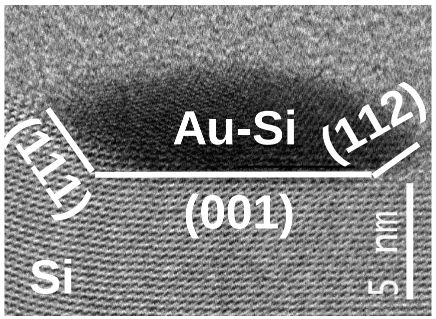
Catalyst diameter **5-15 nm**

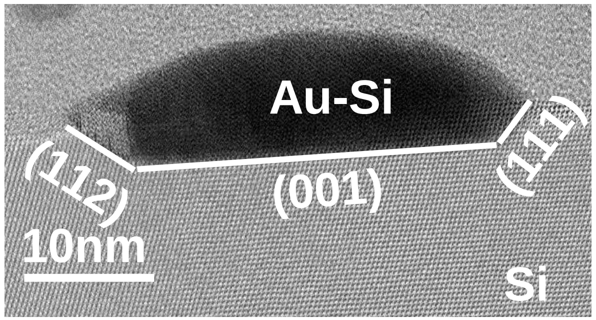


(b)

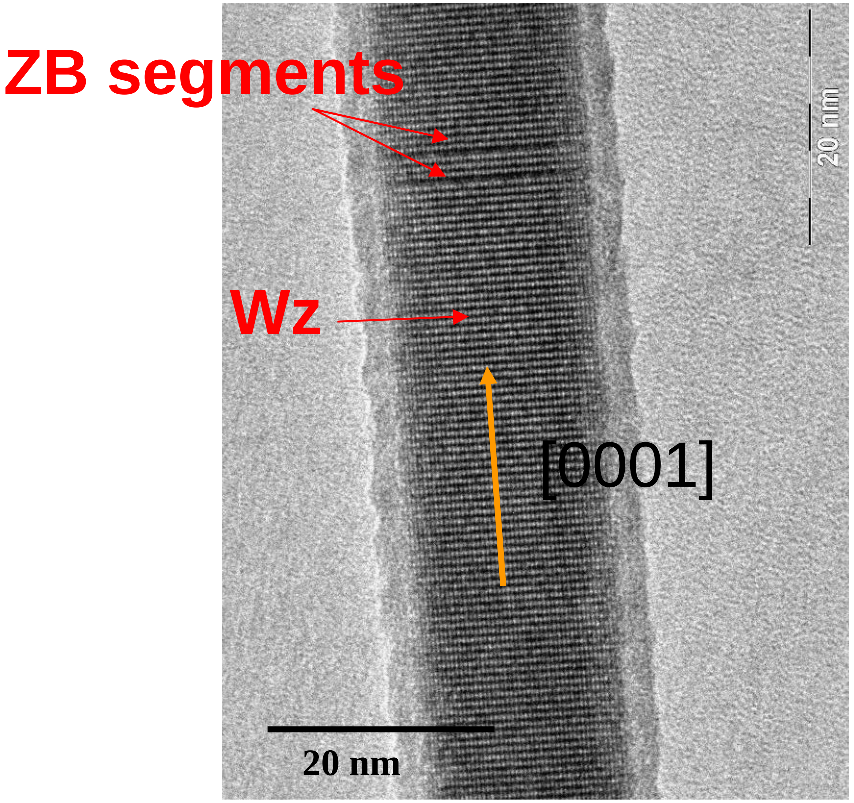
Pencil

Catalyst diameter **15-30 nm**

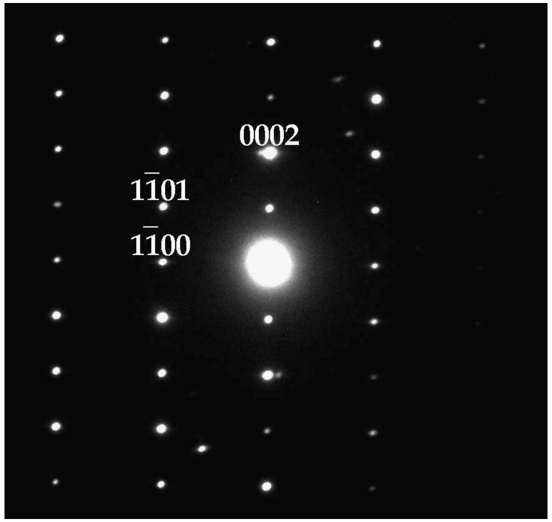




InP NWs on Si(001)



SAED



For needle and pencil NWs:

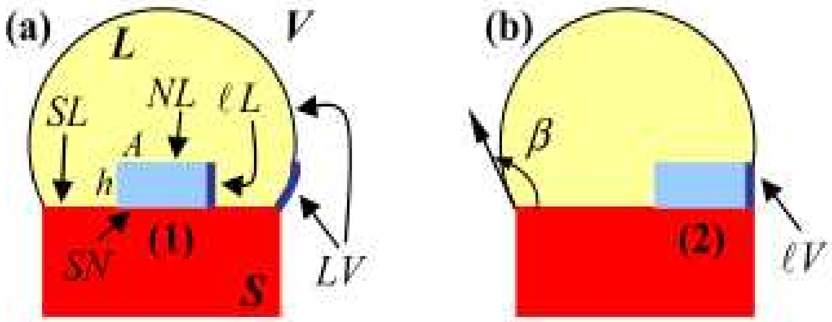
Wurtzite structure with [0001] growth axis

Wz or ZB phase in III-V NWs

F. Glas et al, Phys. Rev. Letters, 99, 146101 (2007)

- Nucleation

With droplet sursaturation



$$\Delta G = -Ah\Delta\mu + Ph\gamma_{\ell L} + A(\gamma_{NL} - \gamma_{SL} + \gamma_{SN})$$

- Wz phase is favored because nucleation takes place preferentially at the triple phase line

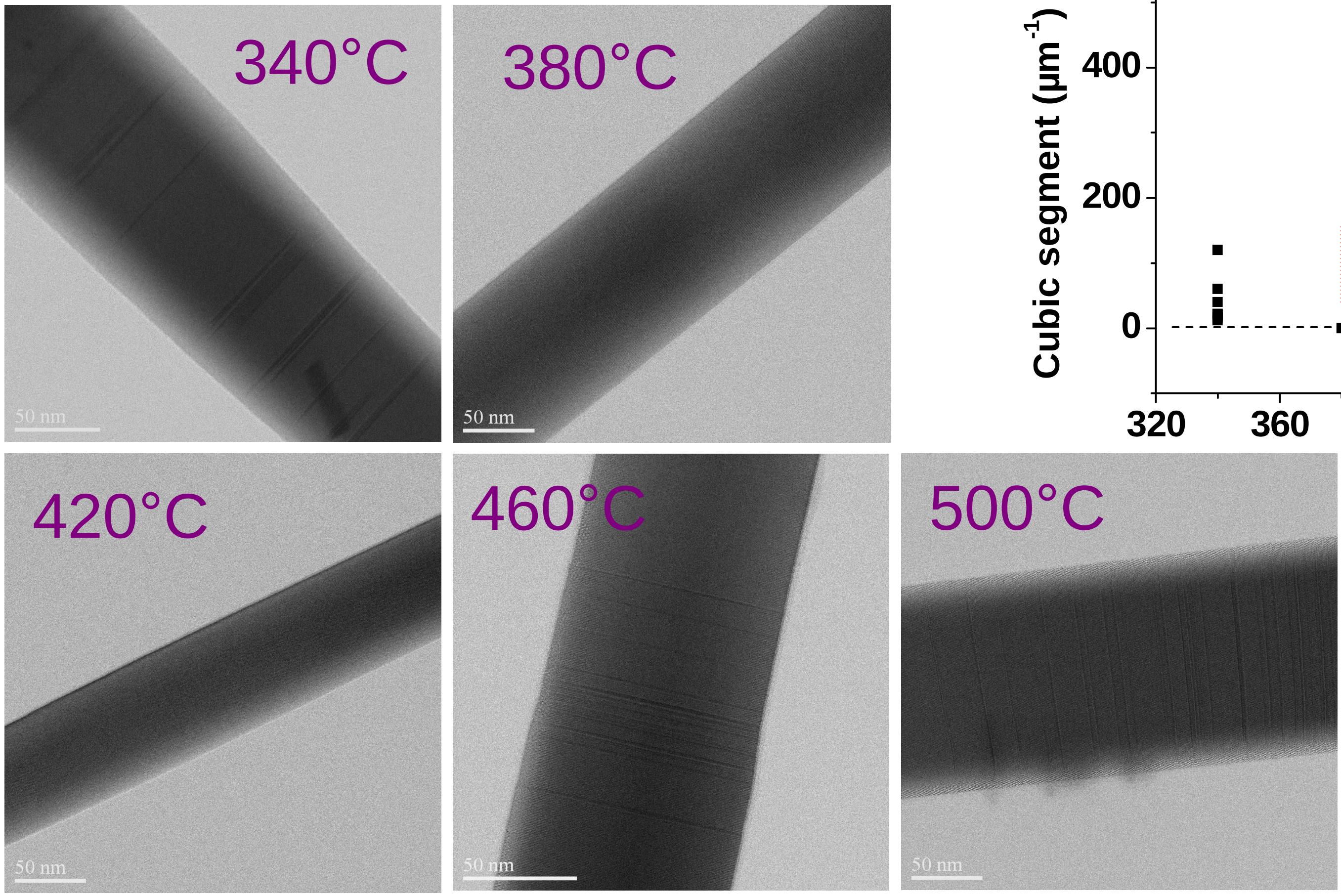
  - If sursaturation superior to critical supersaturation

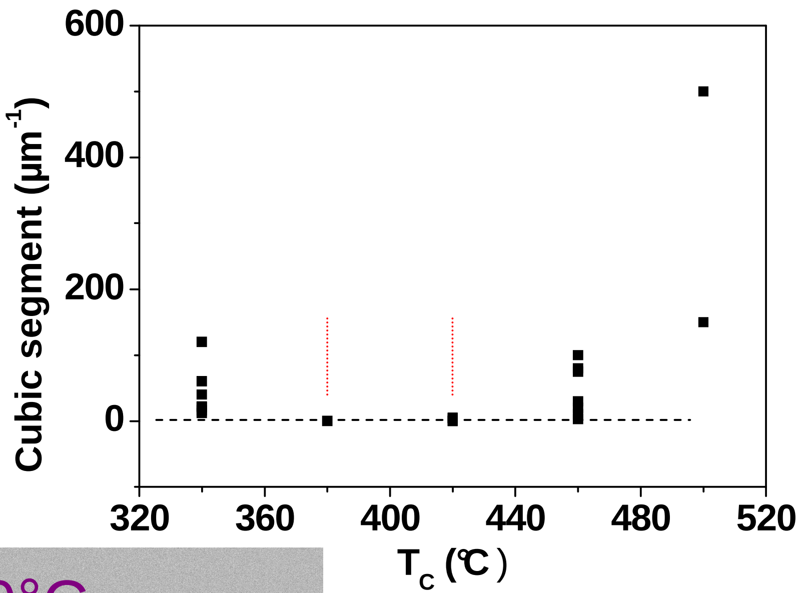
$$\Delta\mu > \Delta\mu_C$$

ZB segment density = f (T_G)

V/III BEP ratio = 19

Au-In catalyst

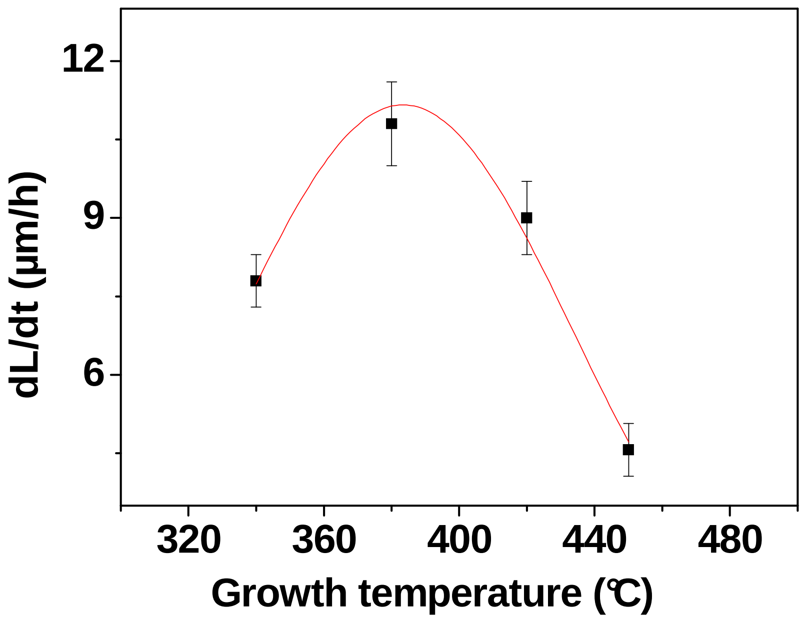


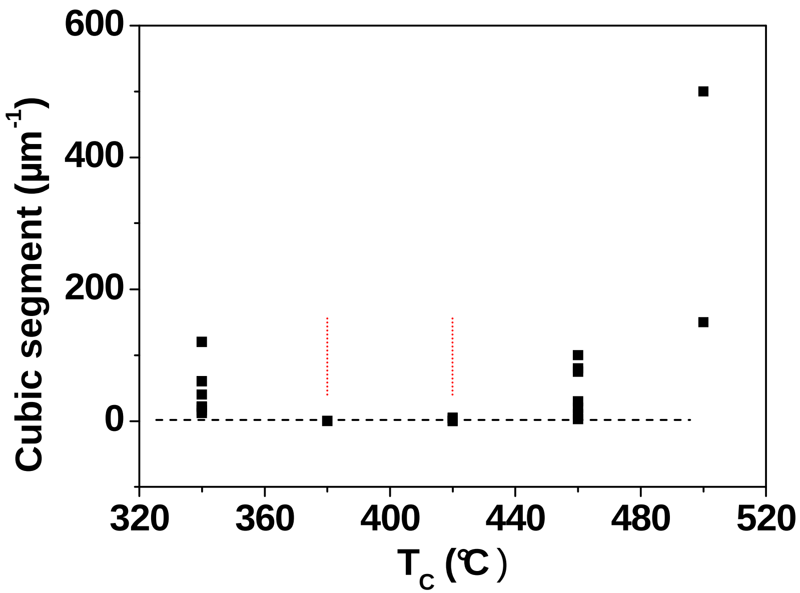


ZB segment density = f (T_G)

V/III BEP ratio = 19

Au-In catalyst





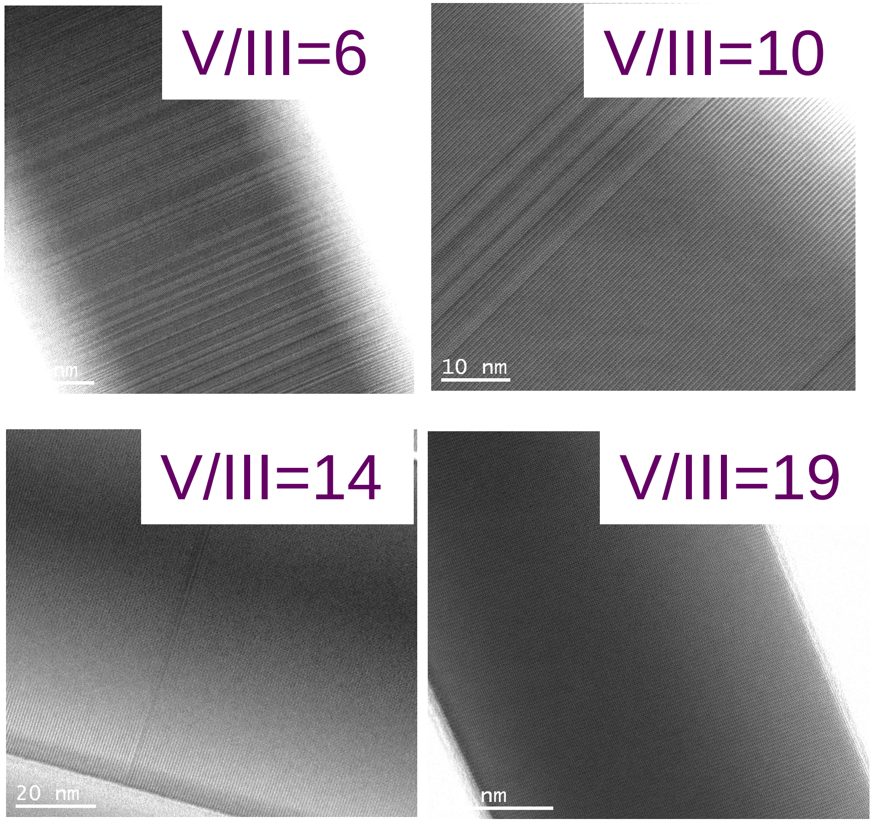
Cubic segments ↘ when axial growth rate ↗

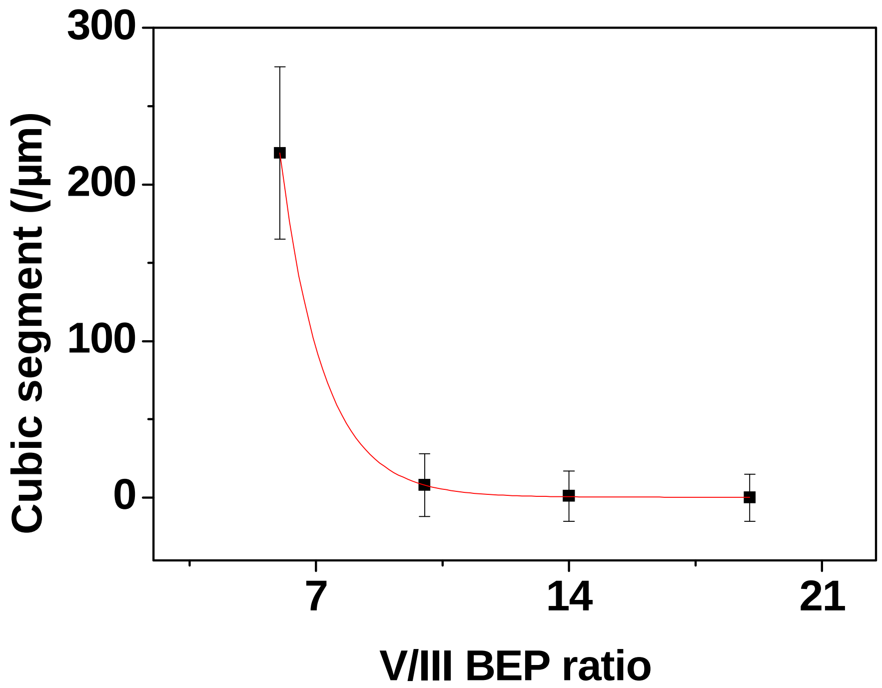
when In-P pair sursaturation ↗

ZB segment density = f (V/III)

T_G = 380 °C

Au-In catalyst



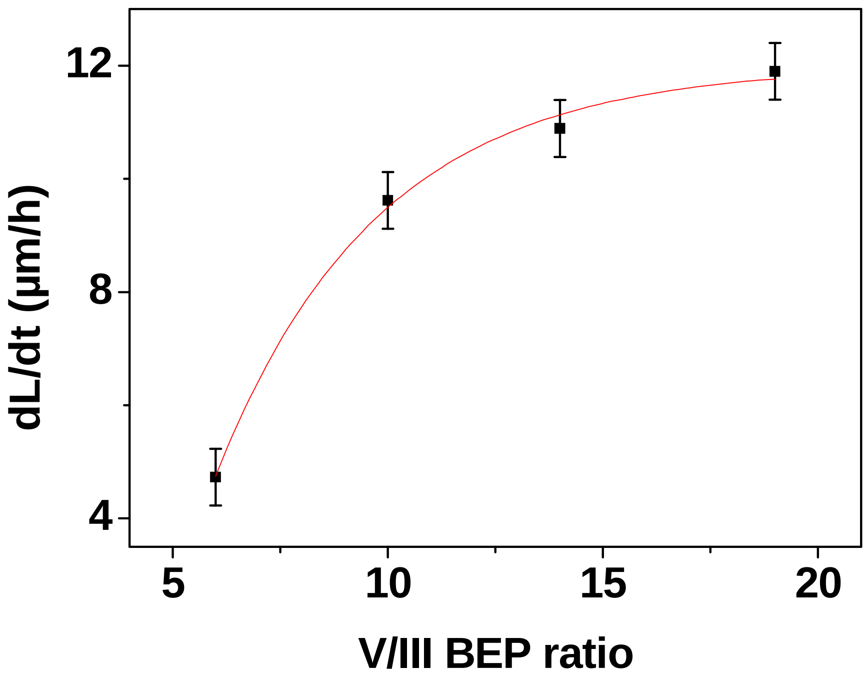


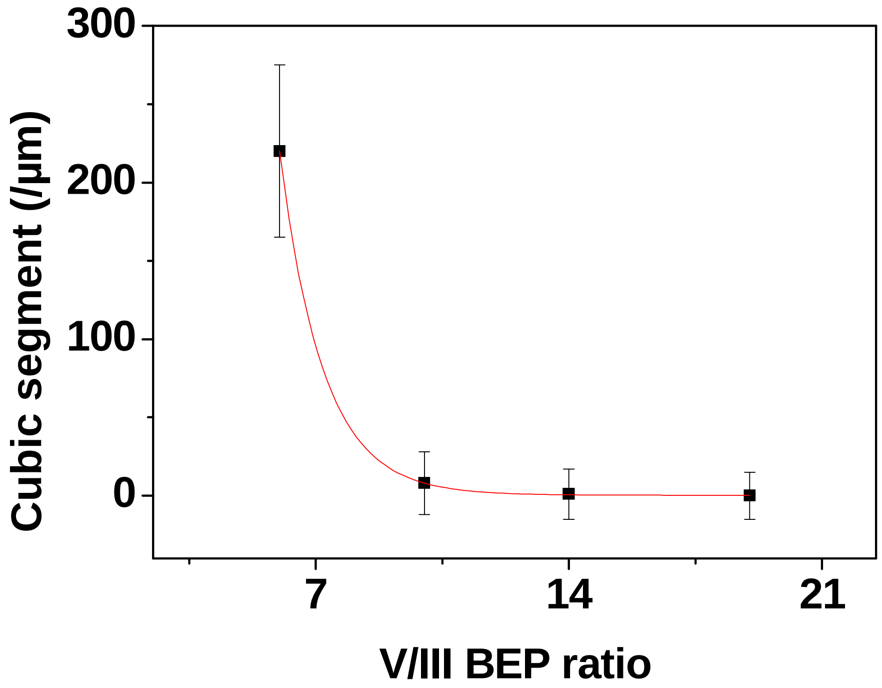
S. Paiman et al, Nanotechnology, 20, 225606 (2009)

ZB segment density = f (V/III)

T_G = 380 °C

Au-In catalyst

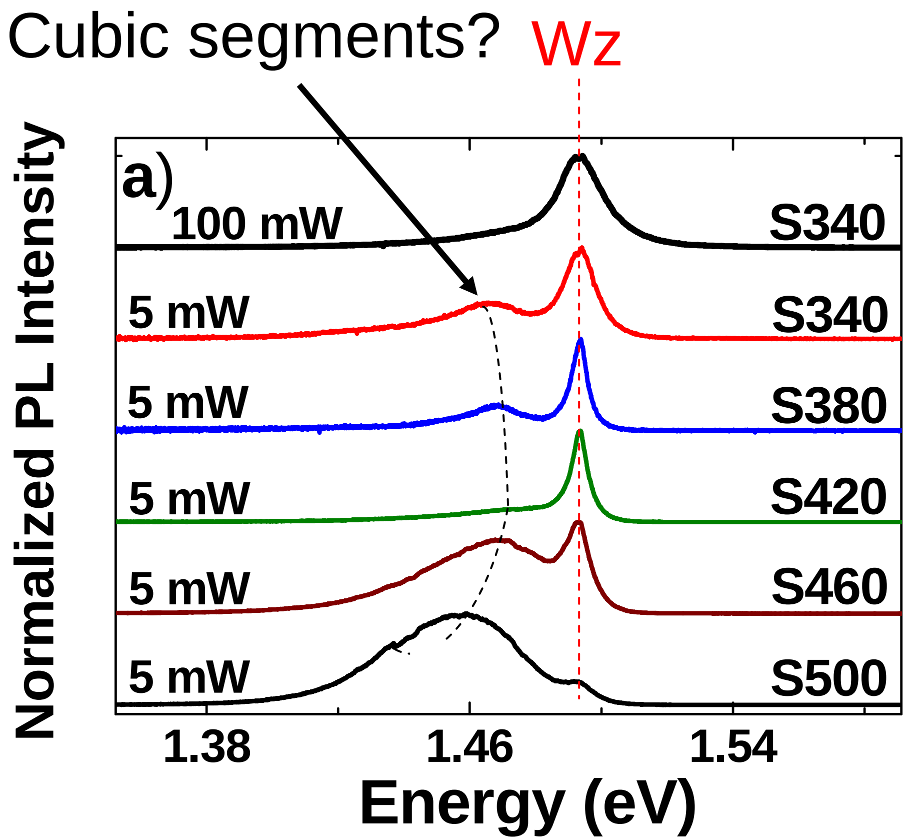


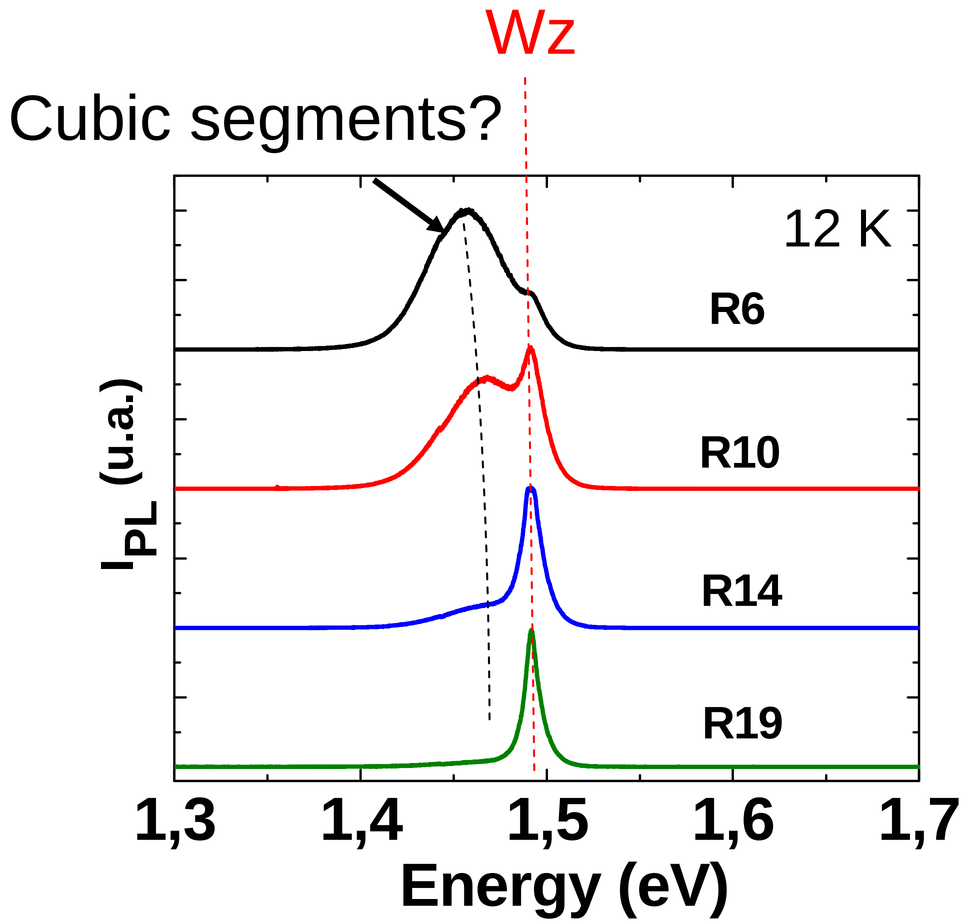


Cubic segments ↘ when axial growth rate ↗

when Phosphorus sursaturation ↗

Optical properties of InP NWs / Si





Type II alignment: ZB segments “superlattice” in Wz structure

N. Chauvin et al, submitted to Appl. Phys. Lett.

☞ To avoid Au contamination

T2.1: Alternative to Au-catalyst (INL, LTM)
The person in charge of T2.1 will be H. Dumont from INL.

☞ self-catalyst (INL + LTM)

☞ catalyst-free (INL + LTM)

☞ Pt-In catalyst (LTM)

Etat de l'art: self-catalyst

APPLIED PHYSICS LETTERS 89, 063119 (2006)

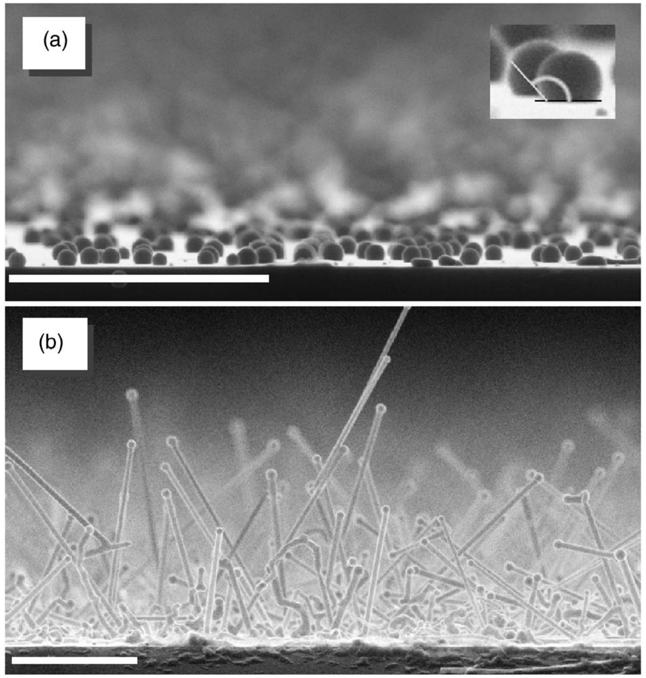
Catalyst-free growth of In(As)P nanowires on silicon

M. Mattila,[a] T. Hakkarainen, and H. Lipsanen
Optoelectronics Laboratory, Micronova, Helsinki University of Technology, P.O. Box 3500, FIN-02015 TKK, Finland

H. Jiang and E. I. Kauppinen[b]
VTT Technical Research Center of Finland, P.O. Box 1000, FIN-02044 VTT, Finland

(Received 30 May 2006; accepted 26 June 2006; published online 10 August 2006)

Native Oxide / Si
+
In droplets



Etat de l'art: catalyst-free

Available online at www.sciencedirect.com
ScienceDirect
Journal of Crystal Growth 298 (2007) 616–619
JOURNAL OF CRYSTAL GROWTH
www.elsevier.com/locate/jcrysgro

Mechanism of catalyst-free growth of GaAs nanowires by selective area MOVPE

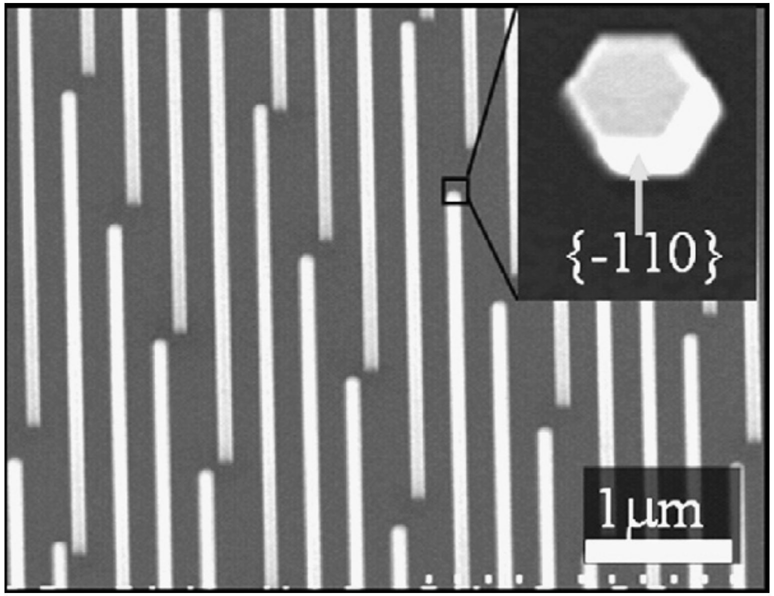
Keitaro Ikejiri, Jinichiro Noborisaka, Shinjiroh Hara*, Junichi Motohisa, Takashi Fukui

Graduate School of Information Science and Technology and Research Center for Integrated Quantum Electronics, Hokkaido University, North 14 West 9, Sapporo 060-8628, Japan

Available online 19 December 2006

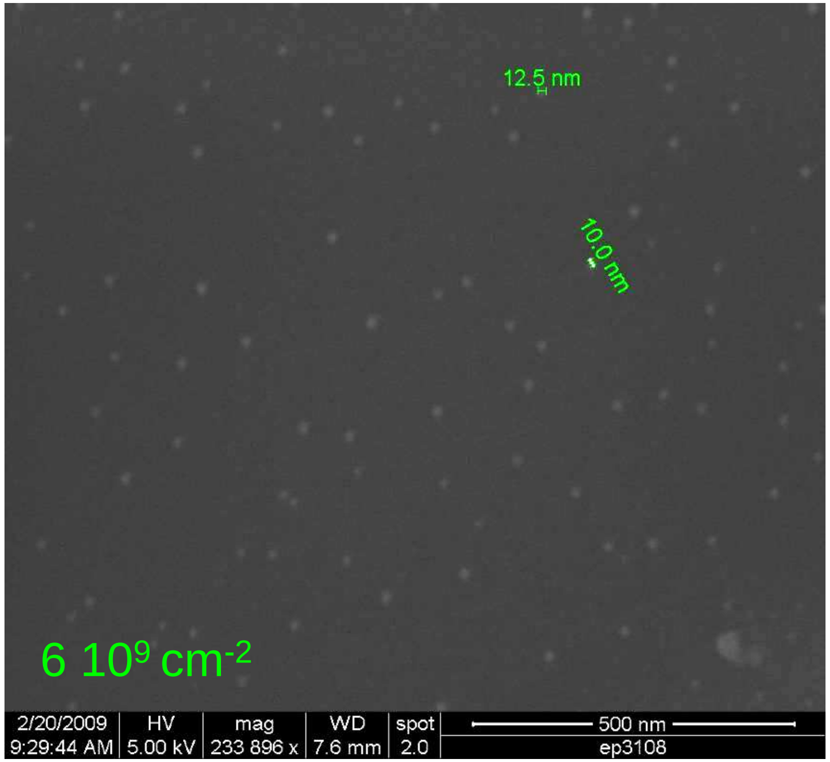
SiO2 mask on GaAs

Catalyst-free

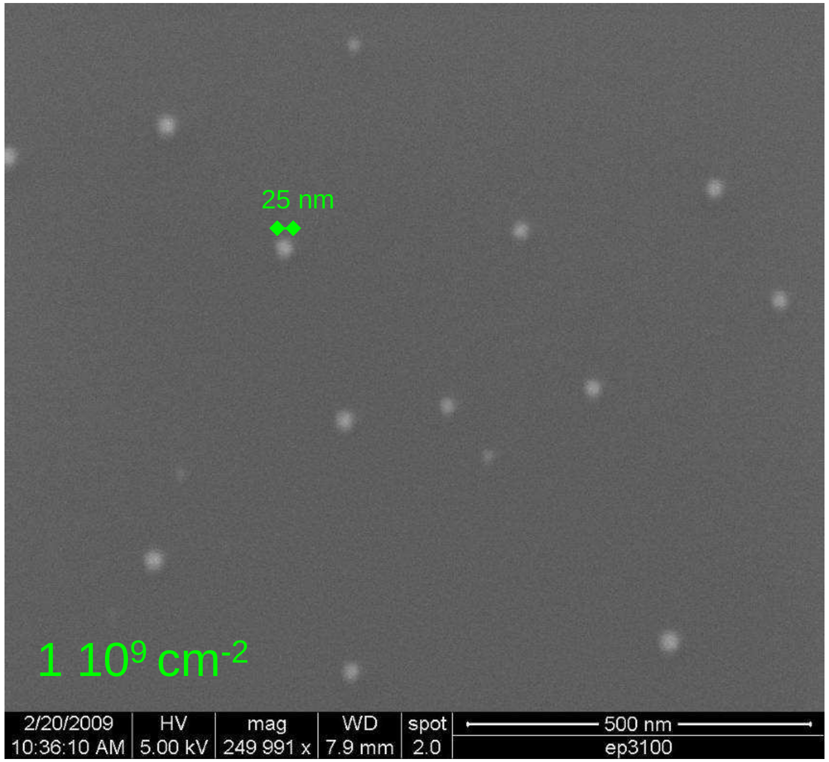


Essai INL: self-catalyst avec gouttelettes d'In

Gouttelettes d'In sur SiO2(ozone)/Si(001) et Si(111)
1MC d'In



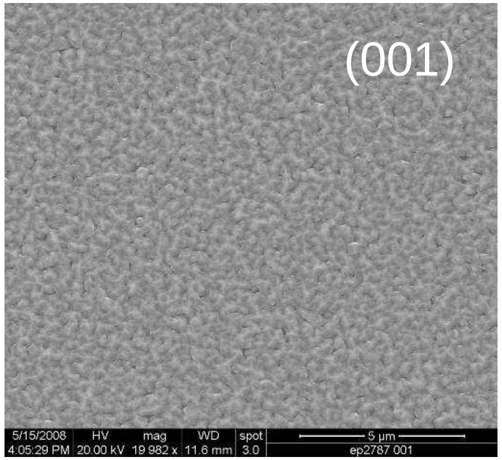
T=280℃

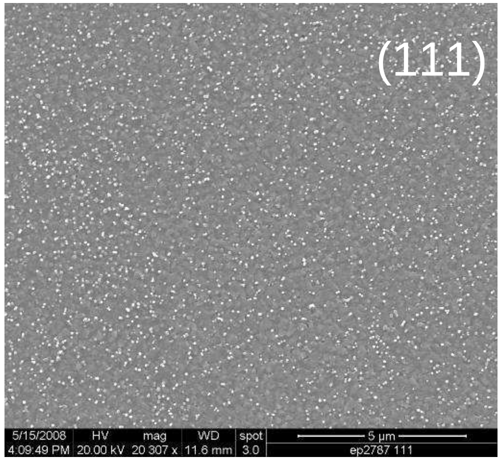


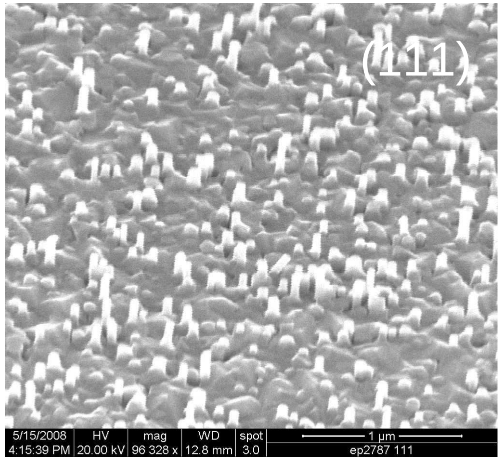
T=350℃

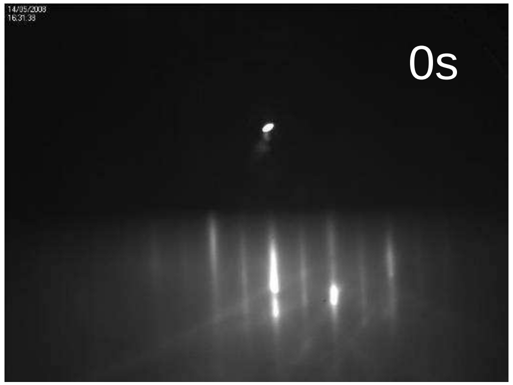
EP2787:InP NWs/ In_g /Si(001) et Si(111)
Lancement du P 10s avant l'In

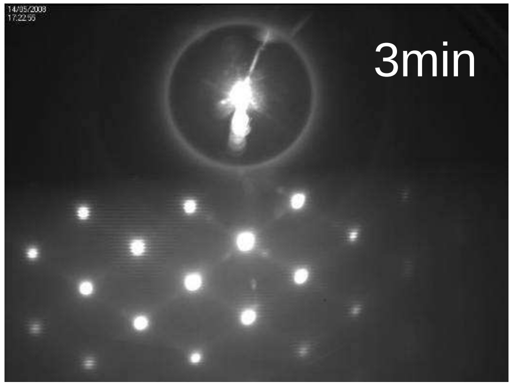
P_P:1x10^{-5}Torr, P_{in}:7.5x10^{-7}Torr, Vc: 1µm/h, t_g: 10min Tc:380℃ (T $_{desox}$550℃)

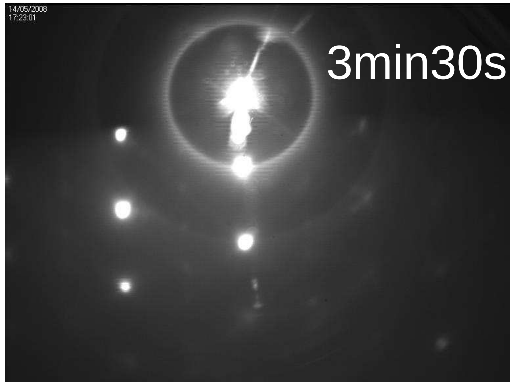










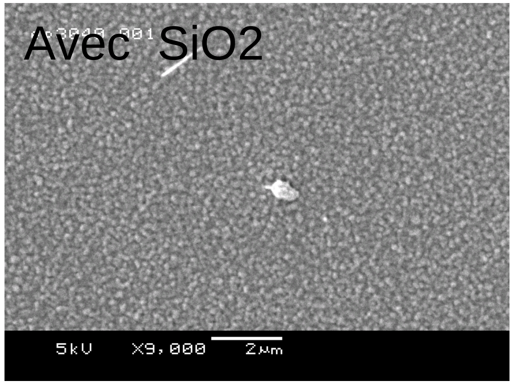


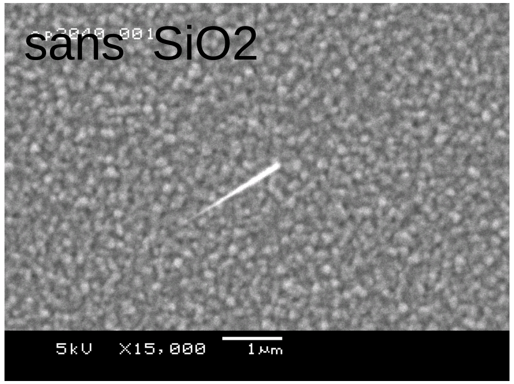
EP3040:croissance avec billes d'In sur :
SiO2/Si(001) et SiO2/Si(111) gravé HF10s sur la moitié de l'échantillon

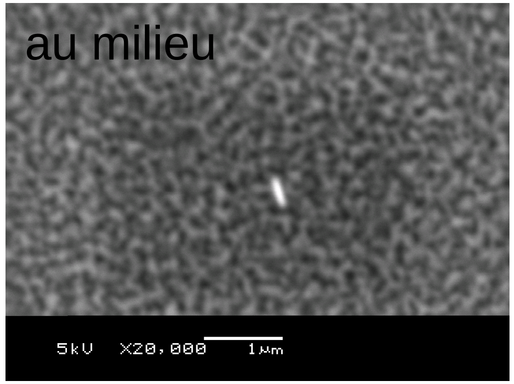
Conditions de depot de billes d'In: T_{desox} 550°C , T_{depot} 350°C, p(In_5) $1.3x10^{-7}$Torr, t 5s

Conditions de croissance: P_P:$1x10^{-5}$Torr, P_{in}:$7.5x10^{-7}$Torr, Vc: 1µm/h, t_g: 10min Tc:380°C

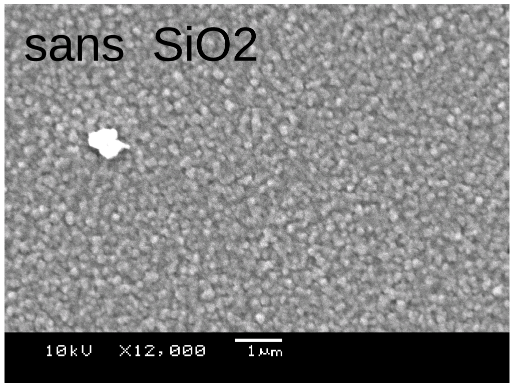
Si(001)

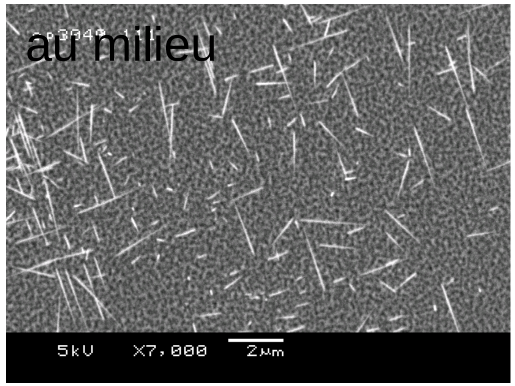






Si(111)

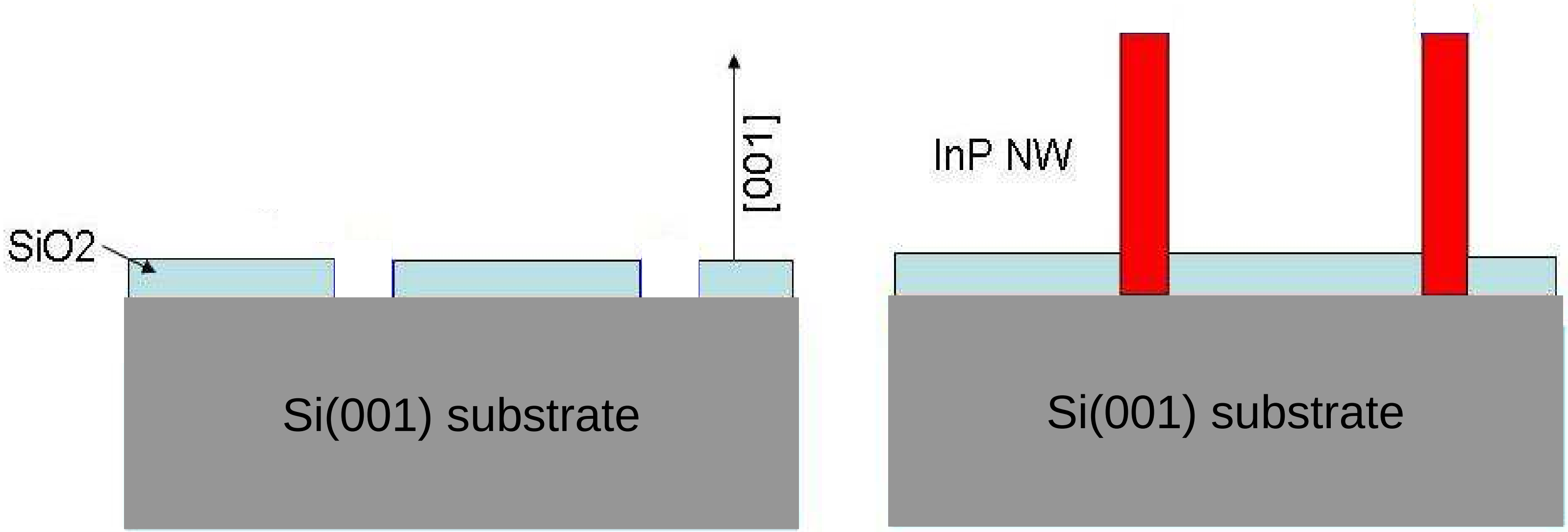




Essai INL: catalyst-free

- To avoid Au contamination
- To avoid the formation of a 2D layer ?

Voir tâche T4

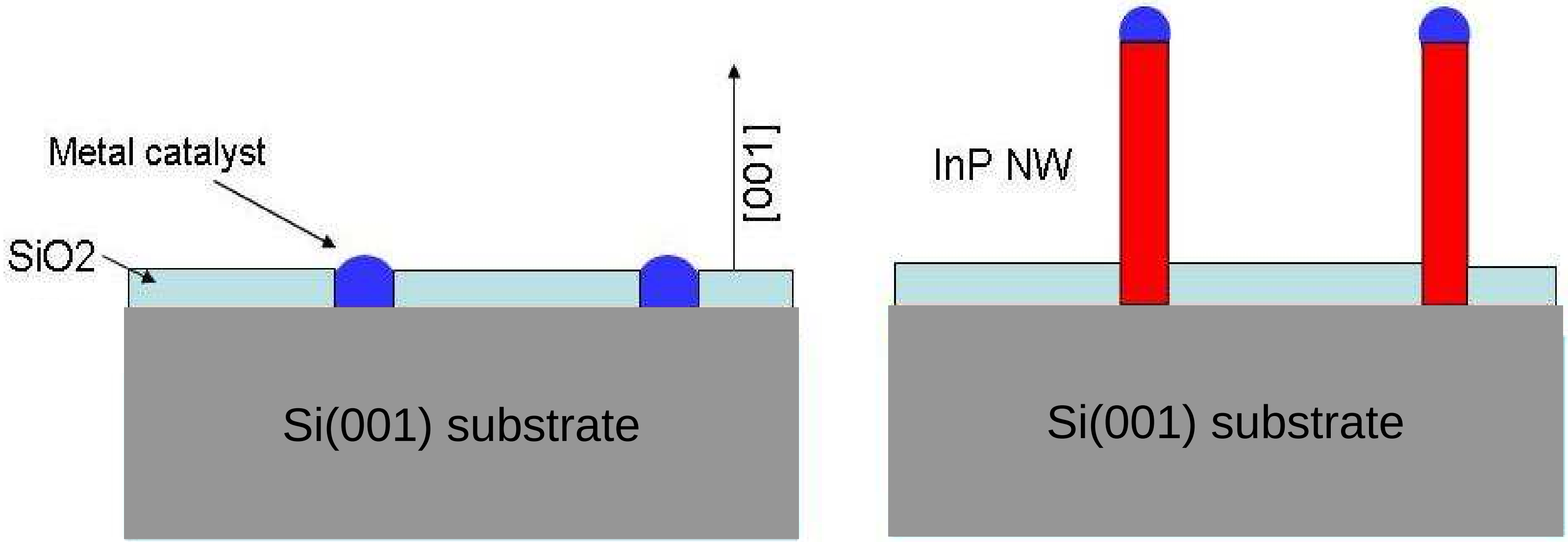


Croissance sélective avec masque de silice ?

Essai INL: catalyst-free

- ☞ To avoid Au contamination
- ☞ To avoid the formation of a 2D layer ?

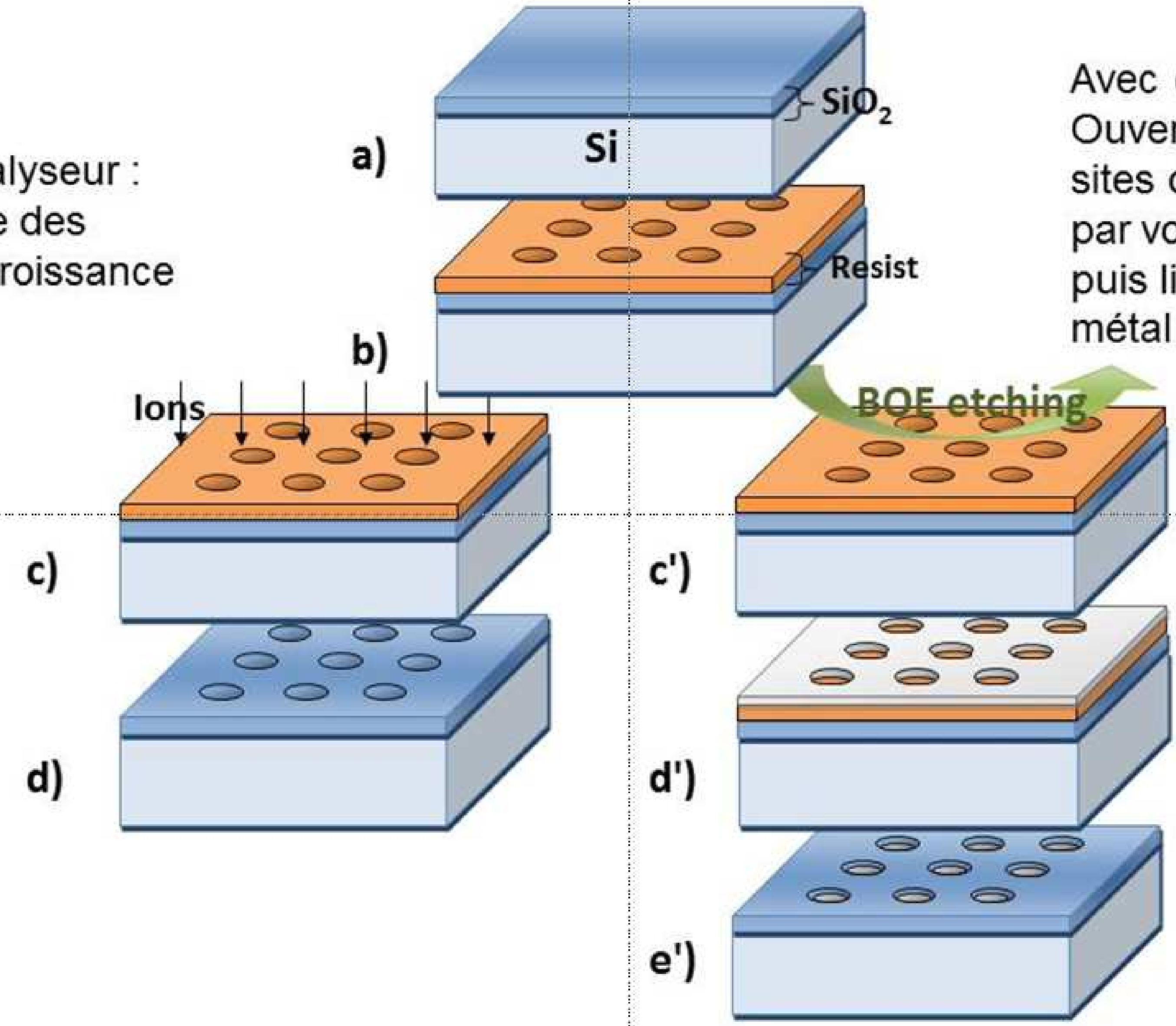
Voir tâche T4



Croissance sélective avec masque de silice ?

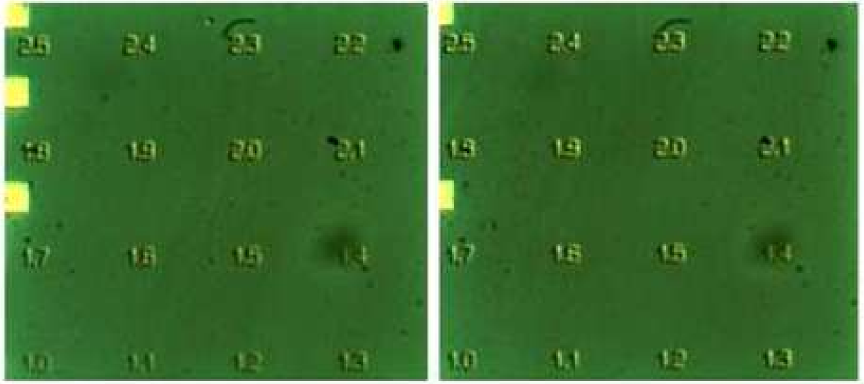
Process

Sans catalyseur :
Ouverture des
sites de croissance
par RIE

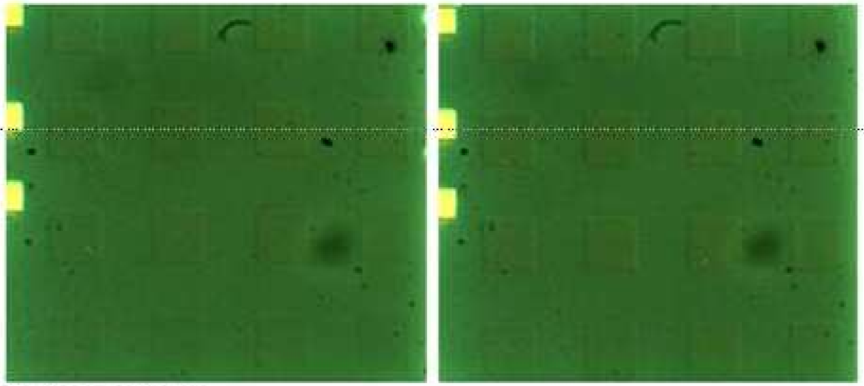


Avec catalyseur :
Ouverture des
sites de croissance
par voie chimique,
puis lift-off de
métal

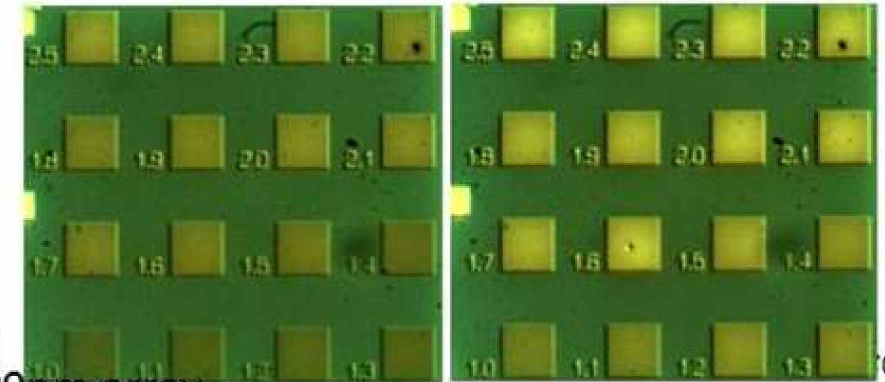
Réseaux de trous de 50 nm à 300 nm



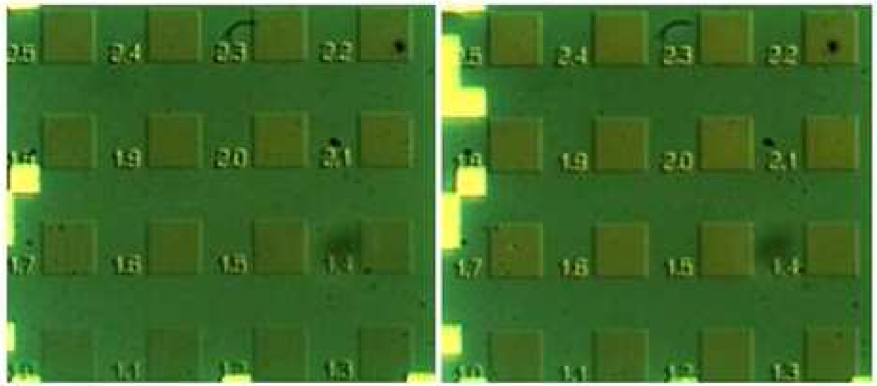
a)
50nm array



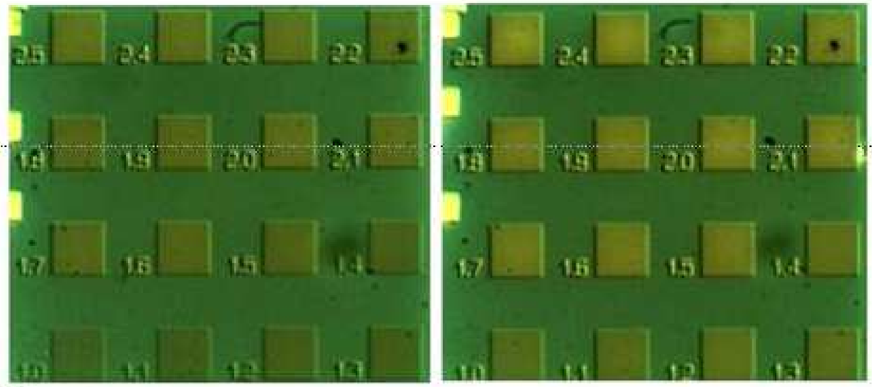
b)
100nm array



e)
300nm array



c)
200nm array

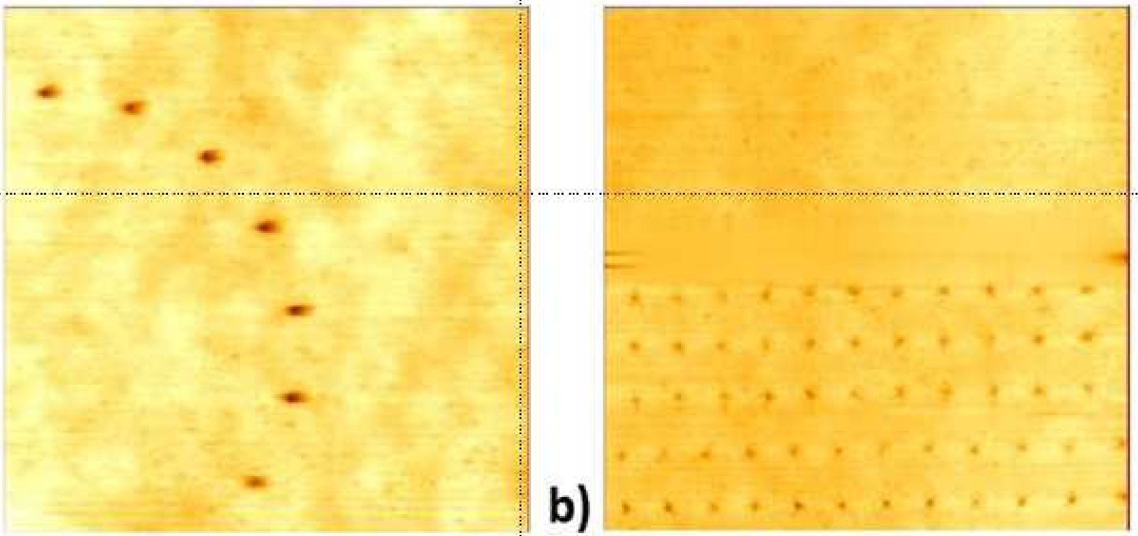


d)
250nm array

Problème : ouverture résine et silice pour les plus petits diamètres (50nm) non résolue

AFM

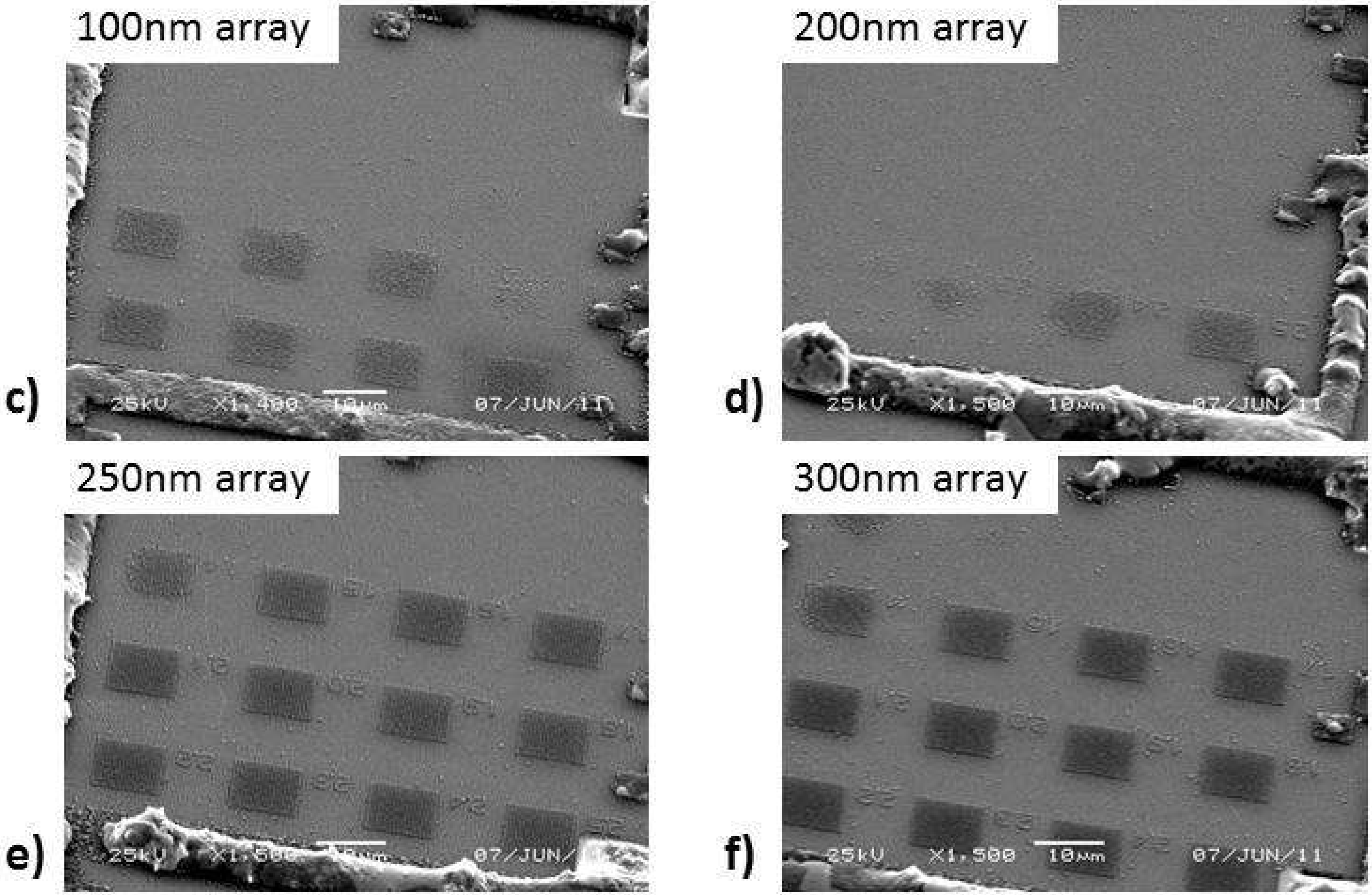
Si <100> 30nm SiO2 (PMMA monocouche, gravure Silice RIE 3').

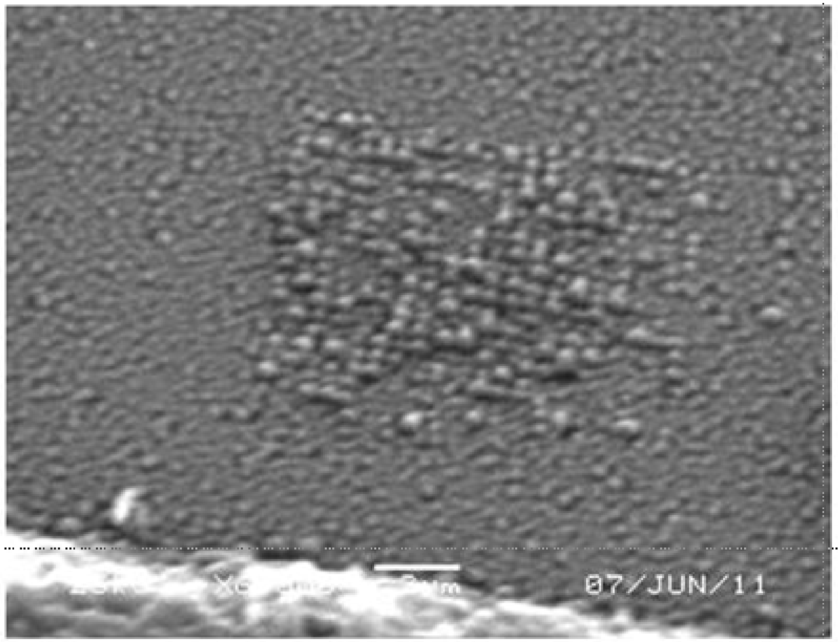


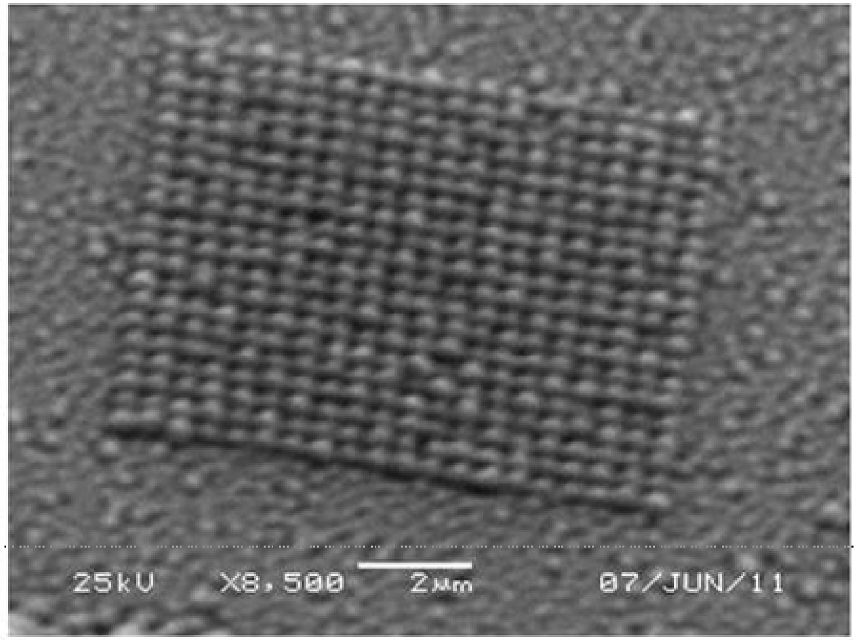
a) b)

Croissance MBE (premiers essais)

Si <100> 30nm SiO2,
RIE 5'.
Épitaxie :
In (1") / In + P (10"),
450°C.
Rapport V/III : 10







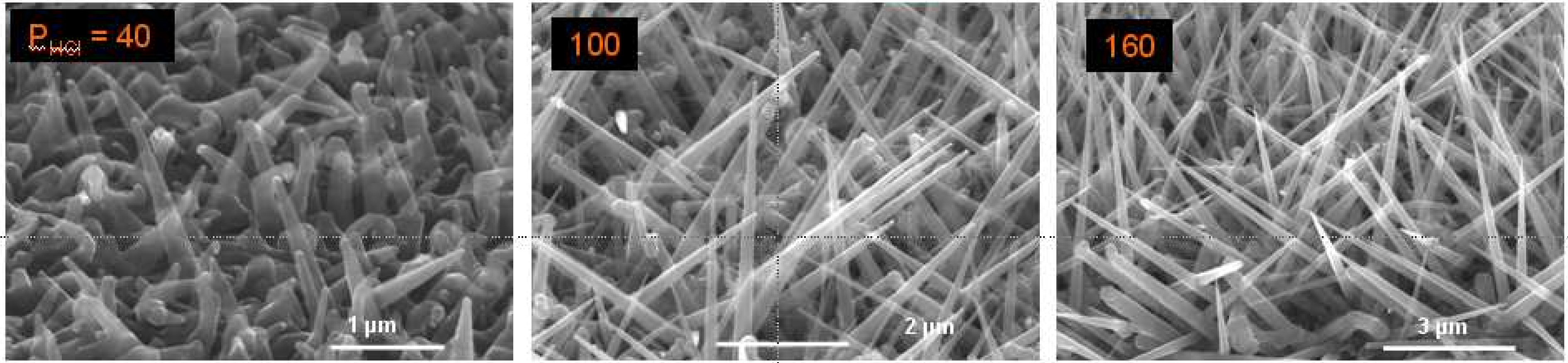
- caractérisation des profils des sites de croissance difficile
    - RIE (profondeur suffisante) / BOE (élargissement des trous)

- Localisation de la croissance d'InP, mais pas de nanofils
    - conditions de lithographie / dépôt à optimiser
    - conditions de croissance à optimiser

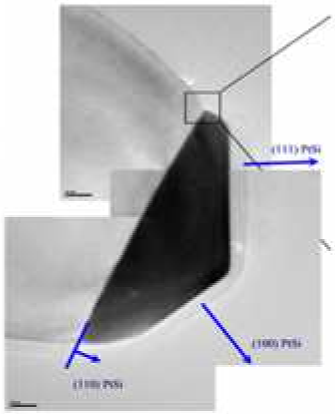
PtSi catalyzed Si NW

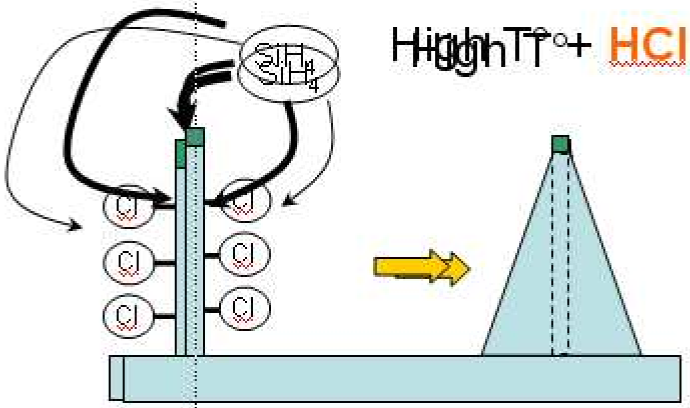
- Introduction of HCl: variation of P_{HCl} (mtorr)

P_{SiH4} = 100 mtorr,
T = 800°C, 10 min

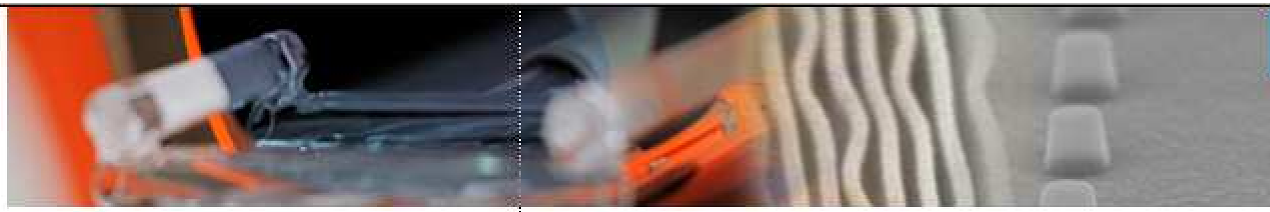


TEM



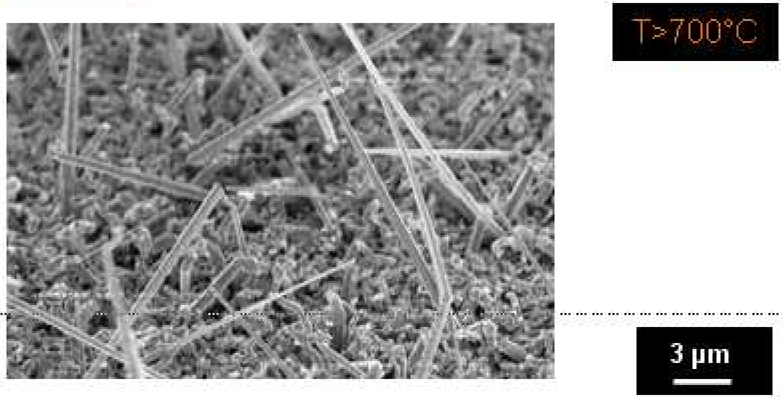


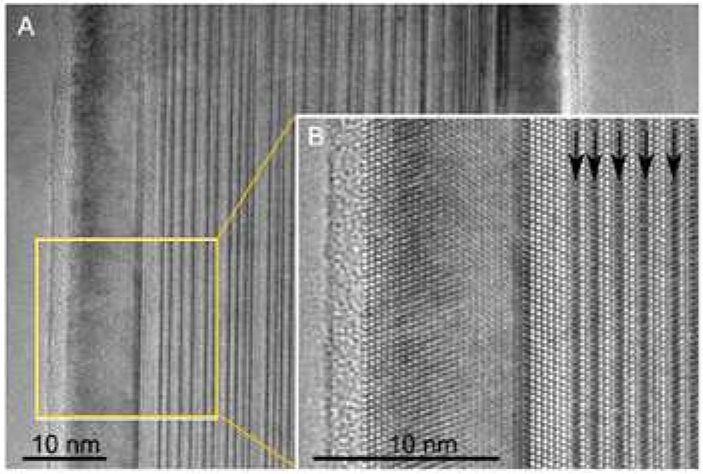
HCl introduction reduces 2D uncatalyzed growth



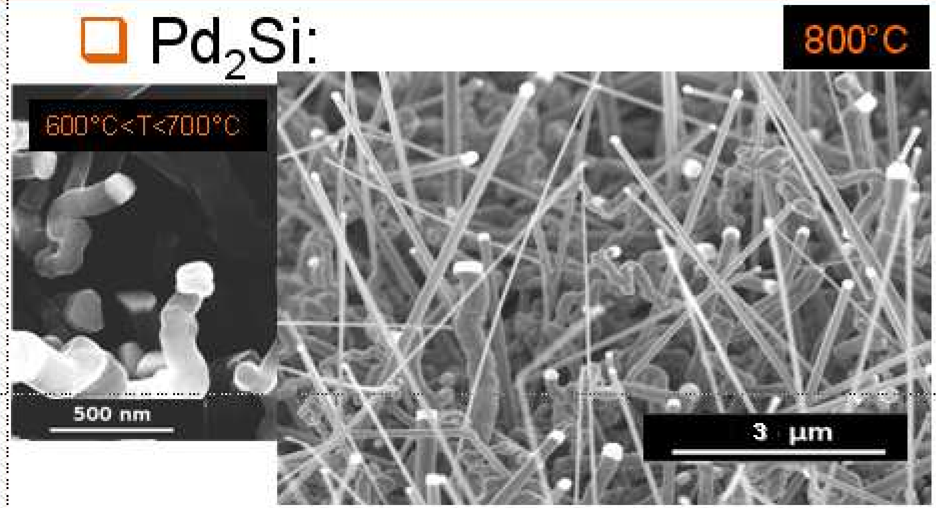
NiSi & Pd_2Si catalyzed Si NW

- NiSi:





- Pd_2Si:



TEM by M. Den Hertog & J.-L. Rouvière

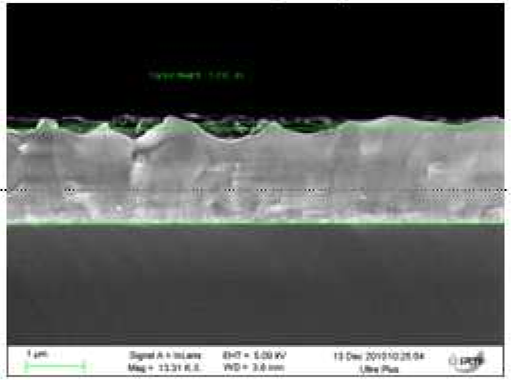
Pd and Ni silicides are also efficient catalyst for Si NWs

Silicides catalysts for SiGe NWs growth

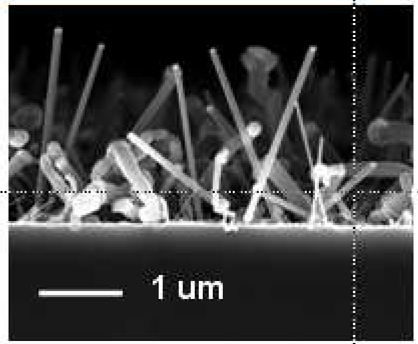
- PdSi, PtSi, NiSi

T° = 650°C, Φ_{SiH4} = 45 sccm, Φ_{GeH4} = 4.5 sccm, P= 4.5 Torr

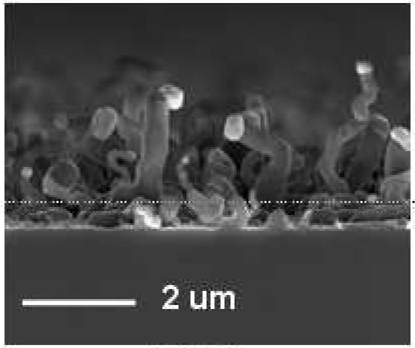
without HCl



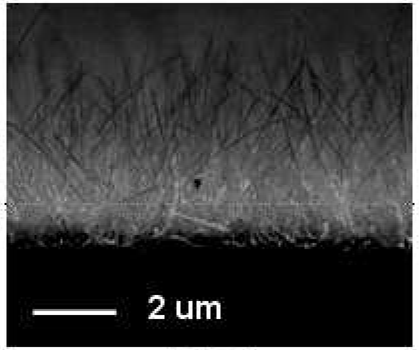
90 sccm HCl



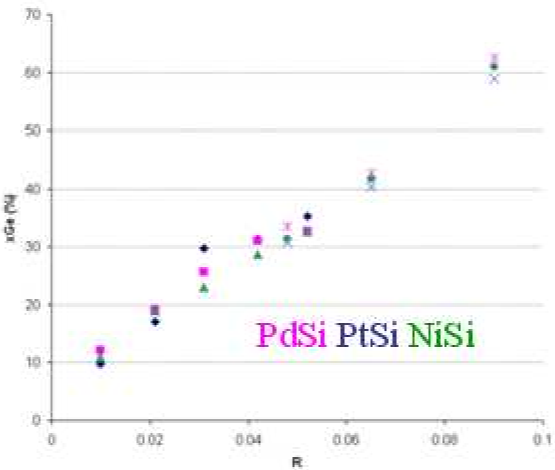
PdSi



NiSi



PtSi

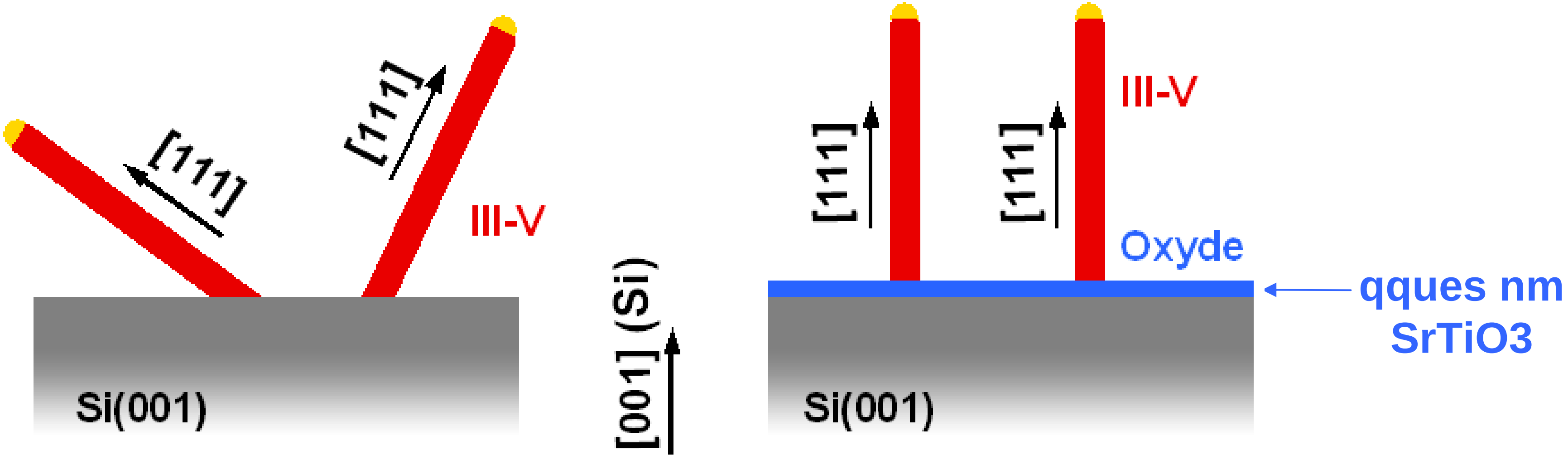


- **Pd, Pt, Ni silicides are efficient catalyst for SiGe NWs growth**
- **Single crystalline NWs**
- **Ge content modulation**

☞ To promote vertically-standing NWs on Si(001)

T2.2: Vertically standing NWs on Si(001) (INL)
The person in charge of T2.2 will be G. Saint-Girons from INL.

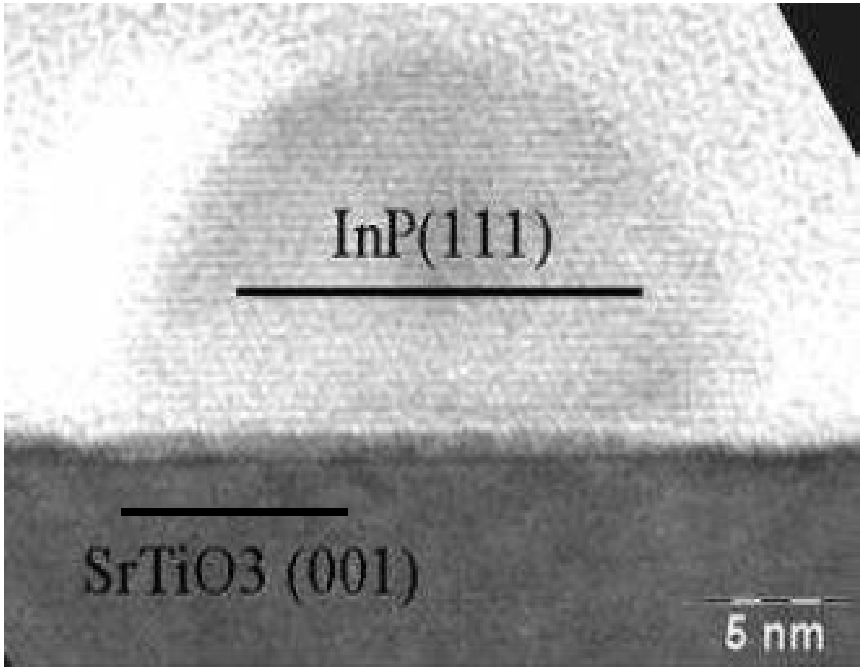
- **Use a thin crystalline oxide SrTiO3 (STO) as buffer layer on Si(001)**

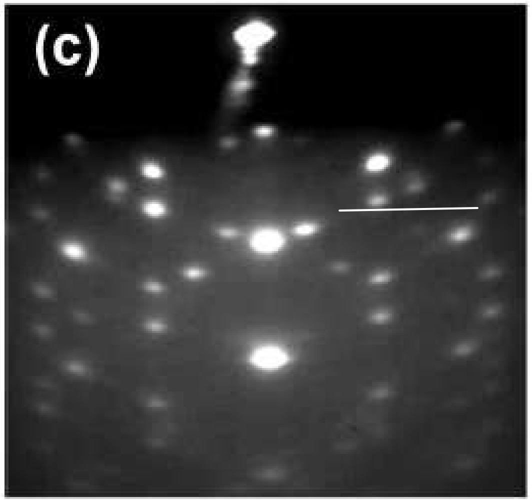


Why STO ?

Work at INL on InP QDs grown on SrTiO3/Si

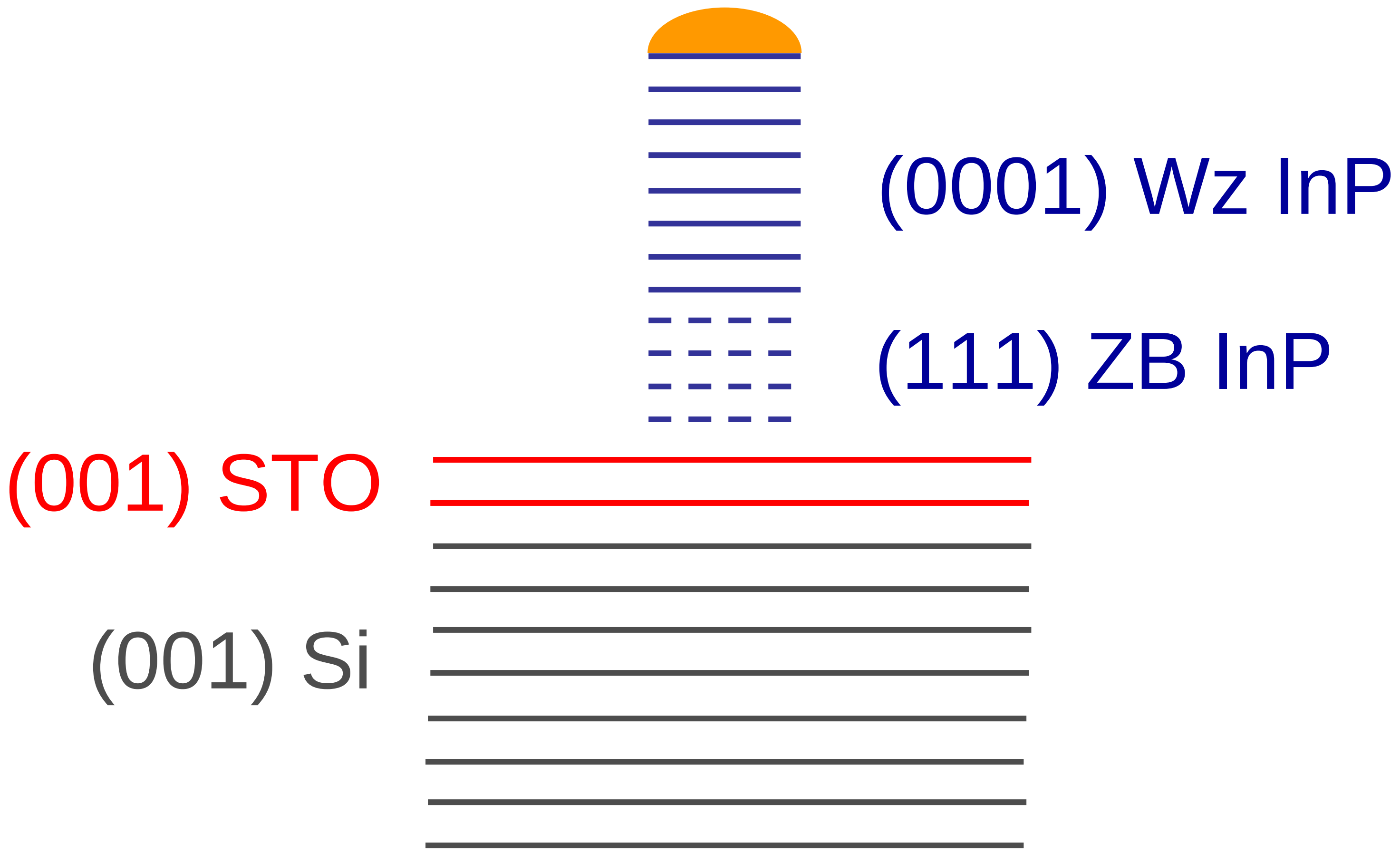
J. Cheng et al , J. of Cryst. Growth, 311, 1042 (2009)
G. Saint-Girons et al, Phys. Rev. B, 80, 155308 (2009)





InP QDs can be (111) oriented on STO(001)

Why STO ?

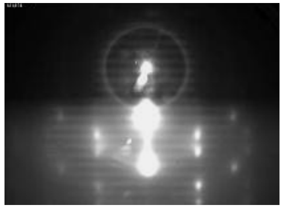


VLS-MBE growth on STO substrate

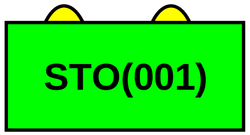
Au dewetting 800°C

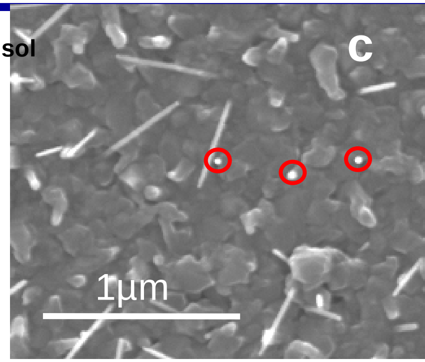
1nm Au

SrTiO3 (001)



Au$_{sol}$





15% Vertical

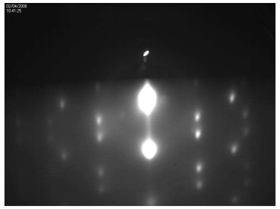
1 10^8 cm^{-2}

Au-In dewetting 770°C

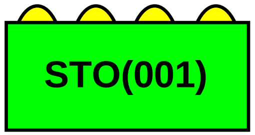
1nm Au

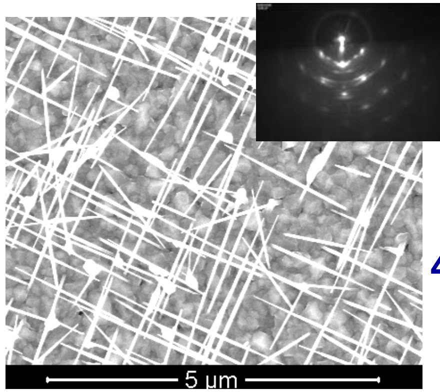
0.5 nm In

SrTiO3 (001)



Au$_{sol}$





0% Vertical

4 10^8 cm^{-2}

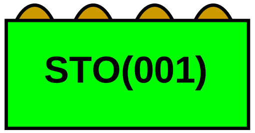
Dewetting 770°C under In flux

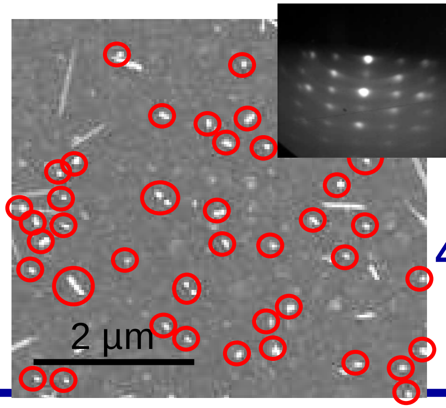
1nm Au

0.5 nm In

SrTiO3 (001)

(Au-In)$_{liq}$





80% Vertical

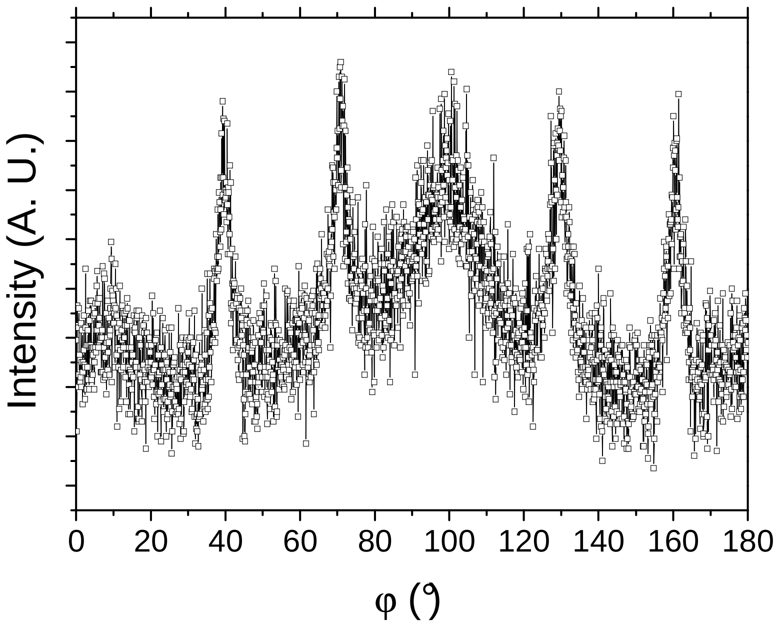
4 10^8 cm^{-2}

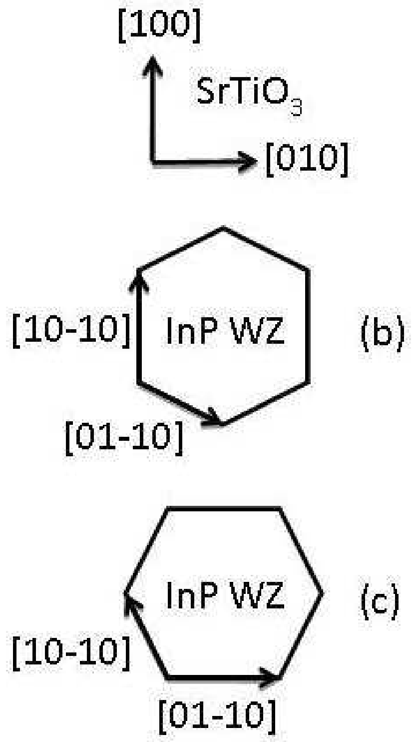
Vertical NWs on STO(001)

X-Ray diffraction:

Pole figure with Wz reflections is not helpful due to the low density of NWs

Azimuthal scan performed at grazing incidence and
at a Bragg angle corresponding to (10-10) InP Wz reflection





STO(001) surface promotes vertical InP NWs

K. Naji et al, to be published in J. Cryst. Growth 2011

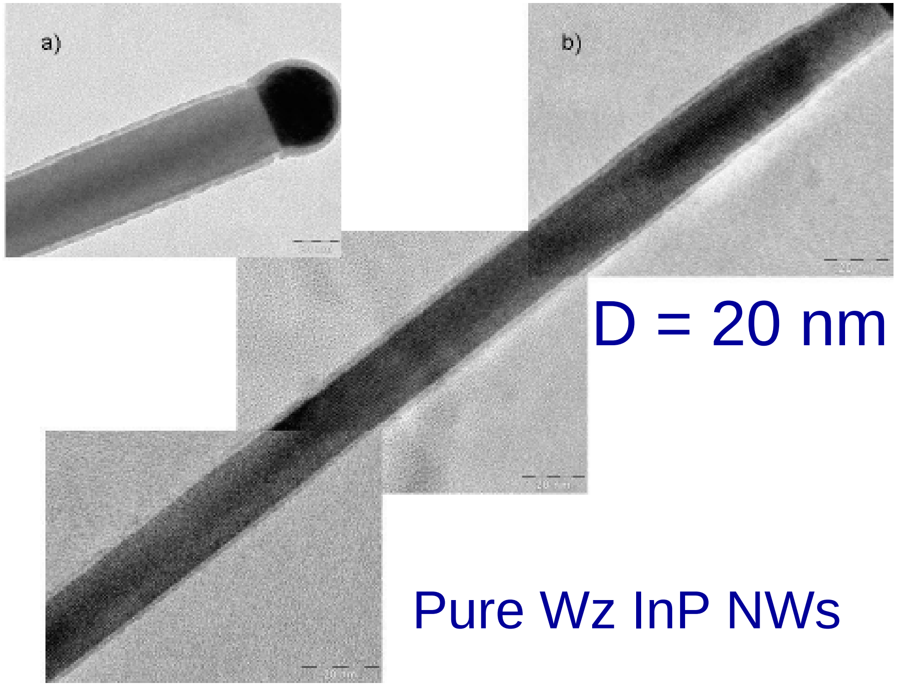
Optical properties

T_G = 380°C,

$P(P_2) = 1x10^{-5}$ torr ($R_{V/III}$ =19)

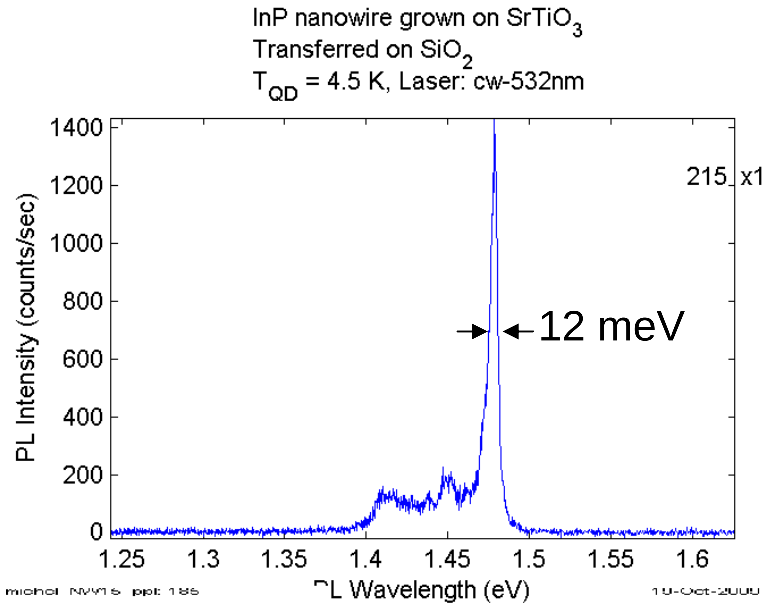
Spectroscopy of
single NWs at 4 K

M. Hocevar and V. Zwiller, KIN, Univ. Delft (NL)



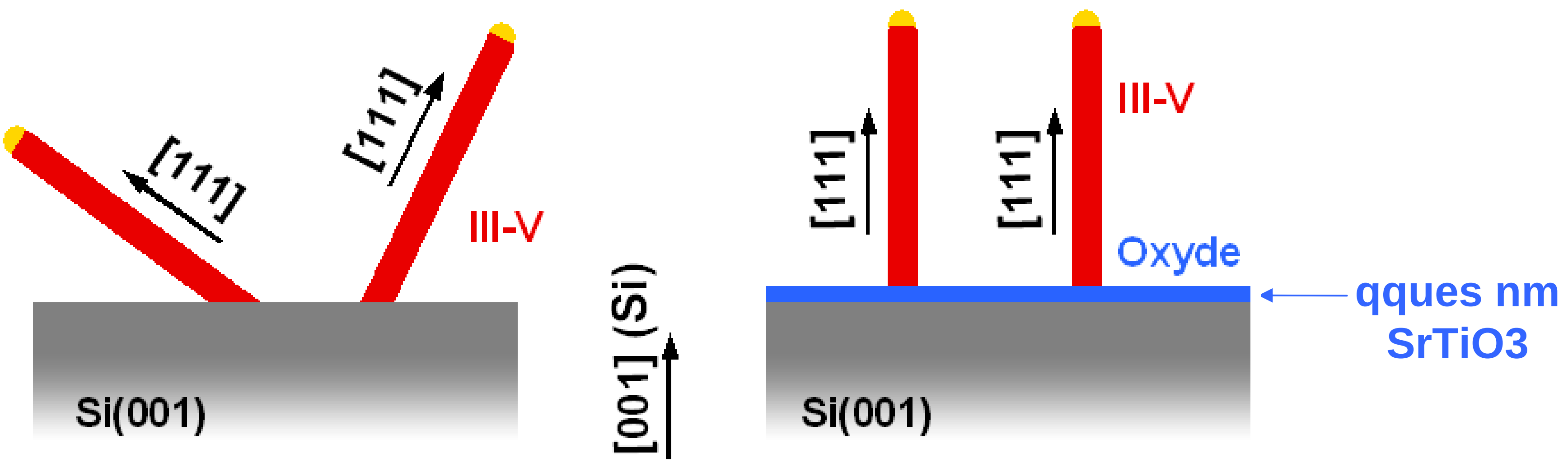
D = 20 nm

Pure Wz InP NWs

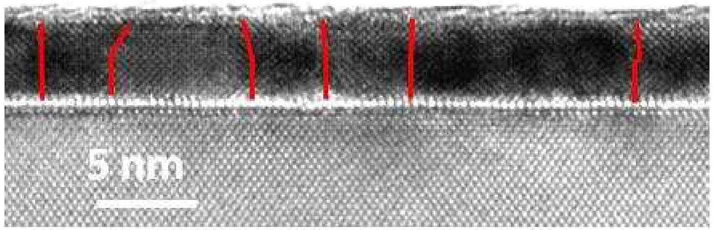


Vertical NWs on STO/Si(001)

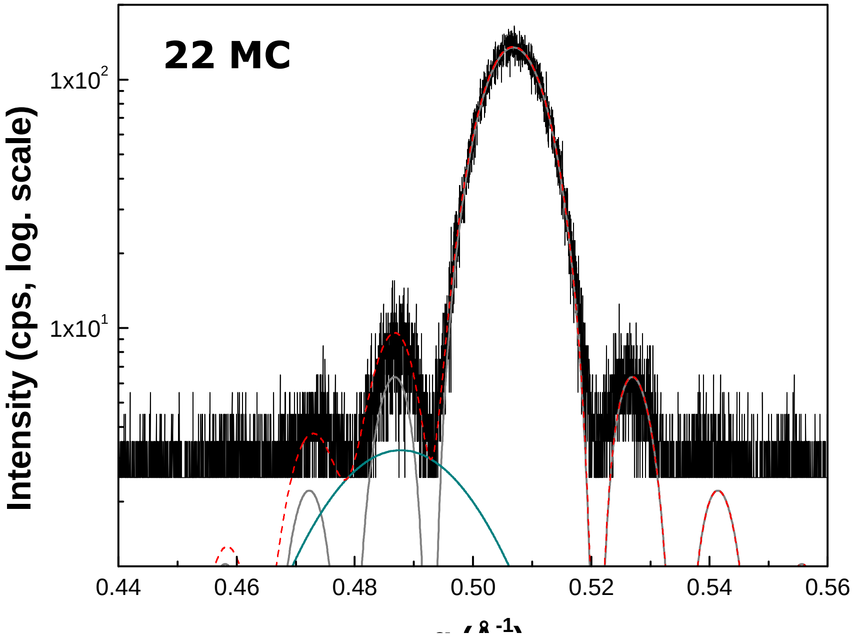
Substrat Si(001) puis SOI(001)

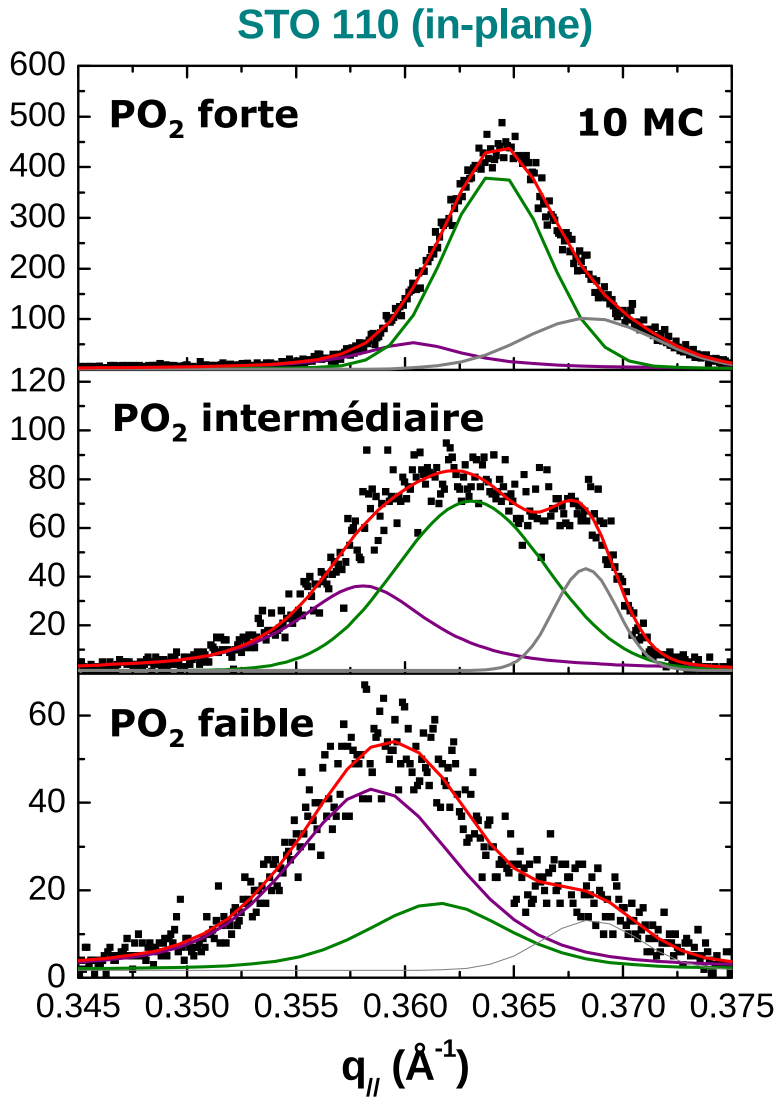


Croissance de STO/Si(001)

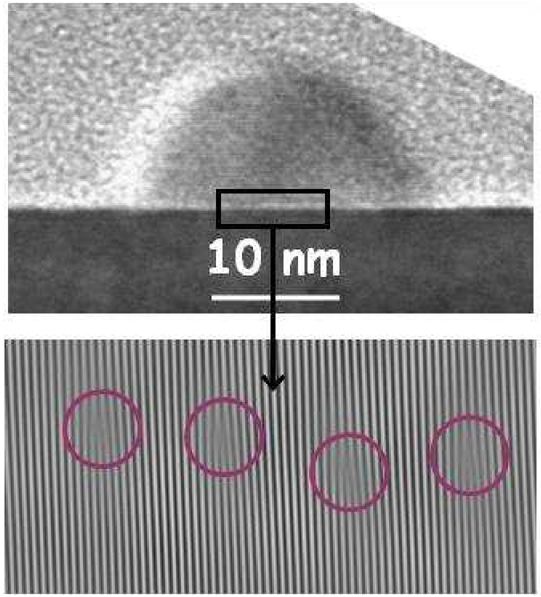


Croissance biphasée : 1 phase lacunaire en oxygène





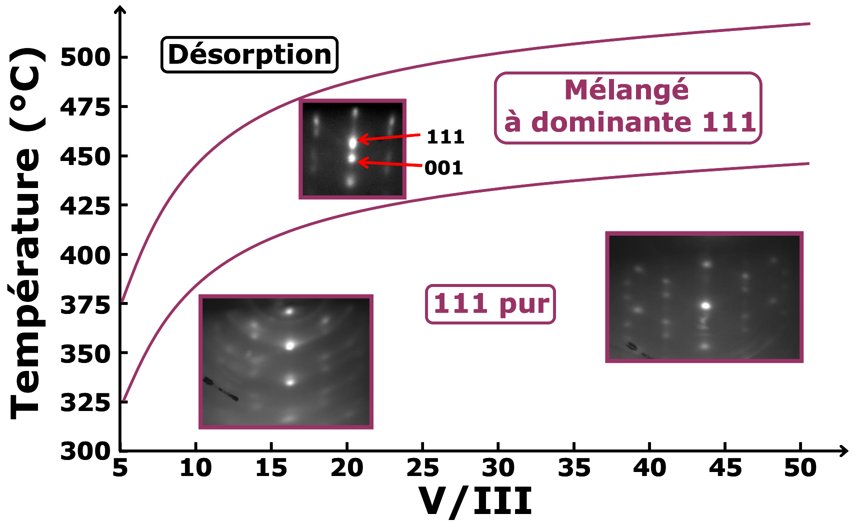
InP/STO : accommodation et orientation



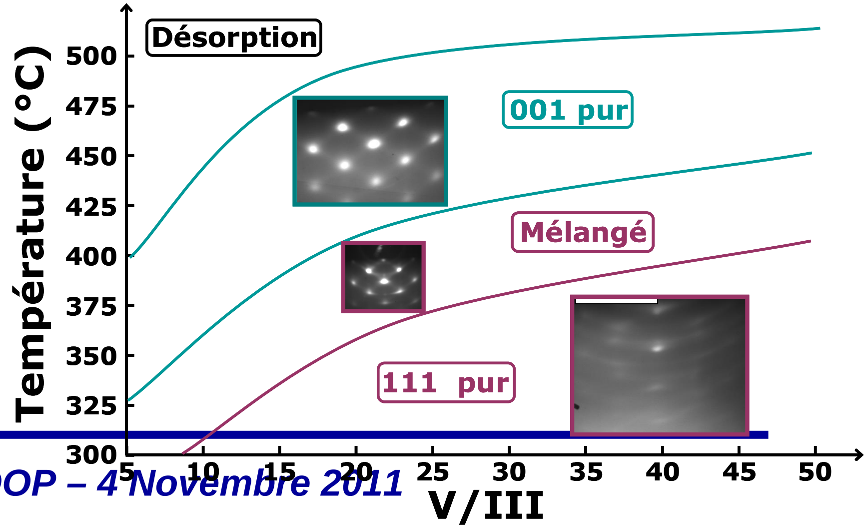
InP relaxé dès le début de la croissance

InP(111) relaxé/STO(001) possible ➔ NF verticaux sur Si(001)?

STO (1x1) TiO_2

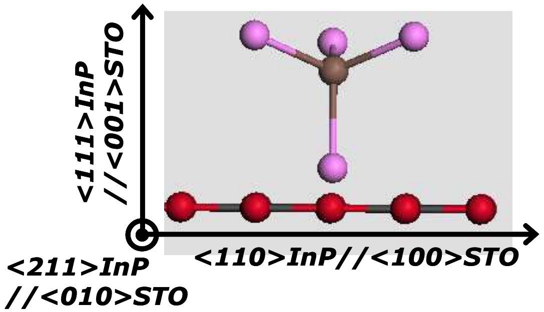


STO (2x1) Ti_2O_3



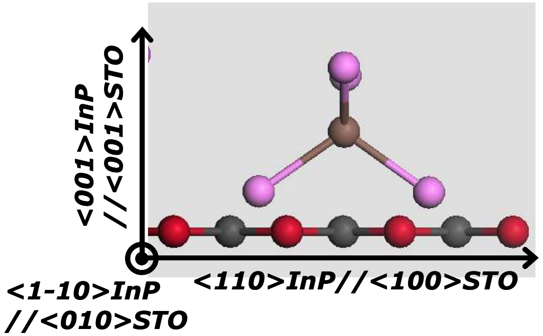
Schémas d'accroche simples : InP/STO(001)

1 patte



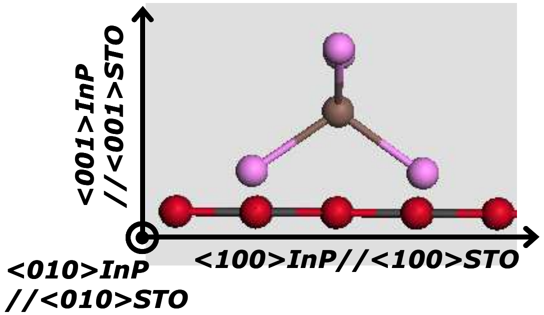
<110>**InP(111)**//<100>STO(001)
<211>**InP(111)**//<100>STO(001)
Δa/a = 6.5% x (-7.9)%
0.064 $Å^{-2}$ O non liés à l'interface

2 pattes direct



<100>**InP(001)**//<100>STO(001)
Δa/a = 50.3% x 50.3%
0 cm^{-2} O non liés à l'interface

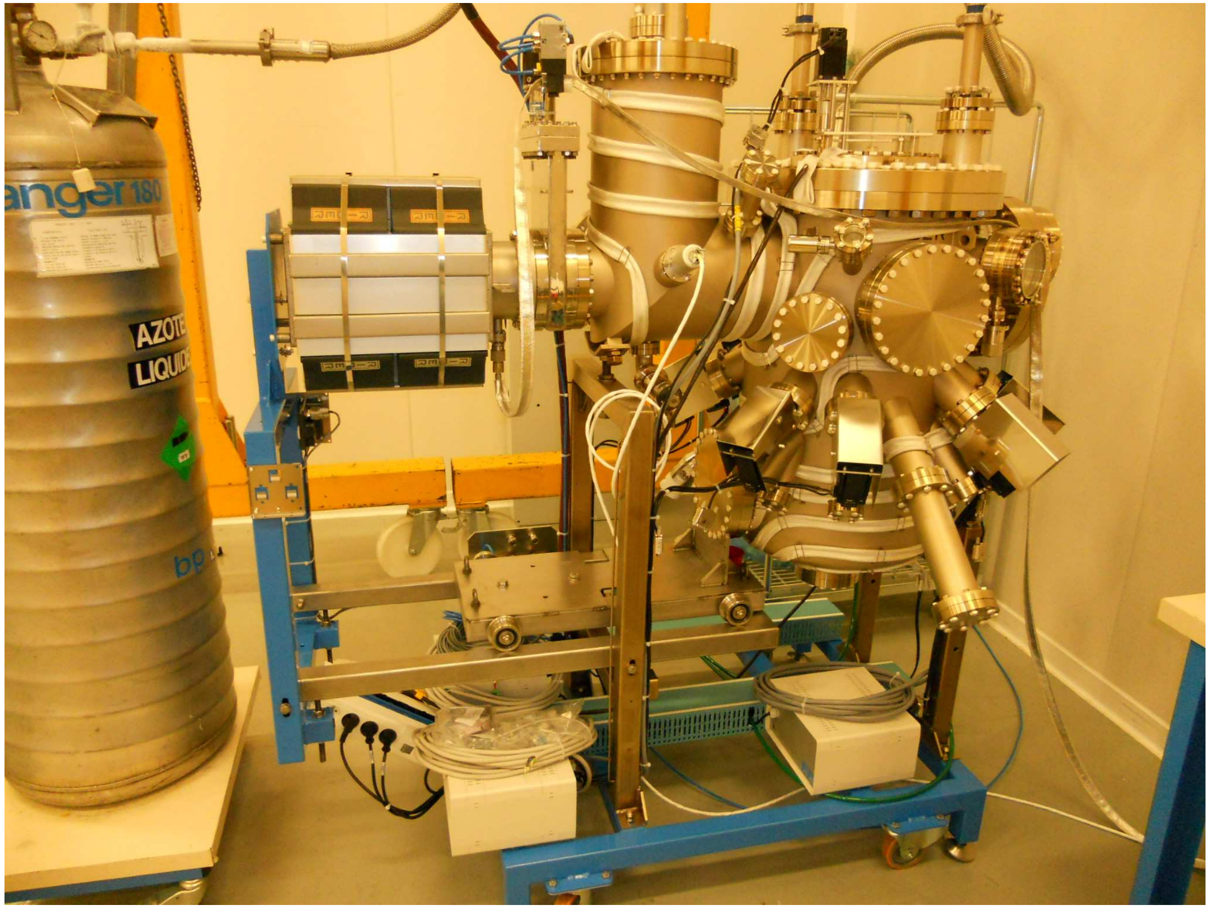
2 pattes 45°



<110>**InP(001)**//<100>STO(001)
Δa/a = 6.5% x 6.5%
0.073 $Å^{-2}$ O non liés à l'interface

Nouveau réacteur oxyde

Riber C21



Objectif : croissance « en recettes » de STO/Si

1ères manip dans ~2 semaines

☞ To promote vertically-standing NWs on Si(001)

- STO/Si(001) template for vertical InP NWs
- Pencil like InP NWs / Si(001) with a Si [115] growth direction for droplet diameter higher than 15 nm (< 30 nm)