INSCOOP

Intégration de Nanofils III-V sur SOI pour COnnections Optiques sur Puce

Réunion T0+18, 9 Avril 2013
LTM/CEA Grenoble

Tâche 2 : Nanowire nucleation and orientation

JB. Barakat-INL, M. Gendry-INL

Arrêt des réacteurs: juin 2012
Remise en marche des réacteurs: décembre 2012- janvier 2013
Arrêt: février 2013

Our work: NWs nucleation and orientation

- T2.1 : Vertically standing InP NWs on Si(001)

Promote vertically standing NWs on Si (001) orientation using a thin $SrTiO_3$ oxide template

- T2.2: Alternative to Au-catalyst

Avoid Au contamination in silicon process lines using alternative catalyst or self-catalysed growth

- T2.3: Selective growth

Avoid the formation of a 2D/3D layer between the NWs by appropriate growth conditions and substrate masking

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Avoid Au contamination in silicon process lines using alternative catalyst or self-catalysed growth … **self catalysis with In droplets**

- T2.3: Selective growth

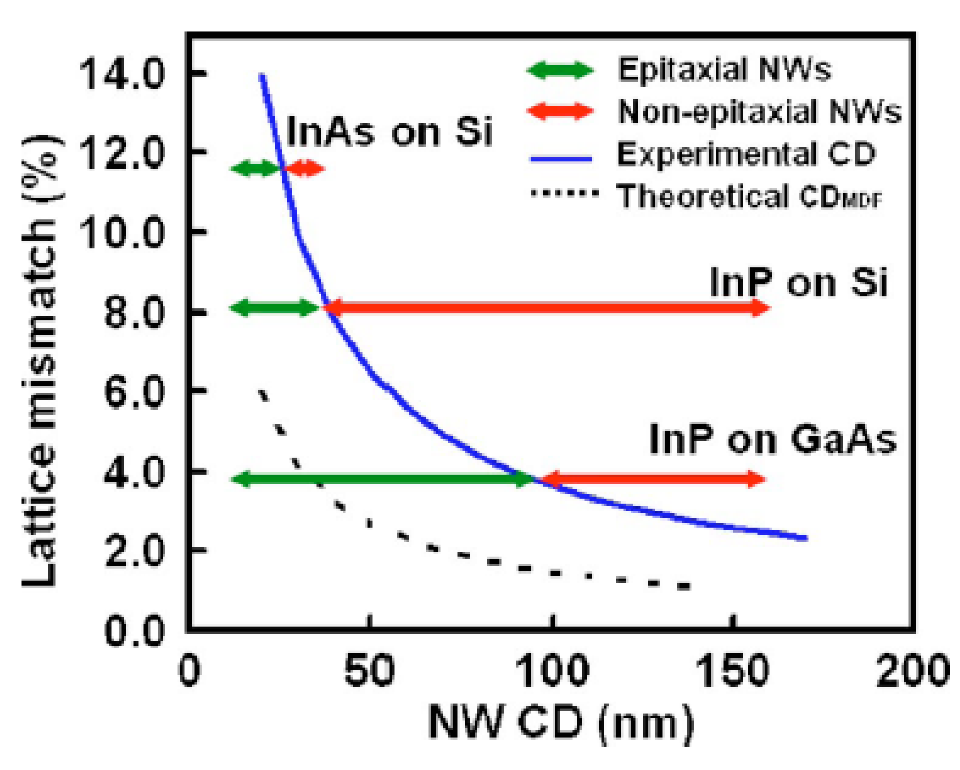
Avoid the formation of a 2D/3D layer between the NWs by appropriate growth conditions and substrate masking

State of the art on self-catalyzed InP NWs

Author	Technique	Substrate	Chemical Treatment	Orientation	Structure
Mattila	MOVPE - VLS	InP(111)	No (native oxide)		ZB
		InP(100)	No (native oxide)	No growth	Ø
		Si(111)	No (native oxide)		WZ
Gao	MOVPE - VLS	Si(111)	Yes (oxide free)		ZB
		Si(001)	Yes (oxide free)		ZB
Ivanov	MBE-VLS (InAsP)	Si InP	*Nanotechnology*, 24, 085707 (2013)		

Mattila et al, App. Phys. Lett. 89, 063119 (2006)   *Gao et al, Nano Lett., 9, 2223-2228 (2009)*

Which droplet diameter?

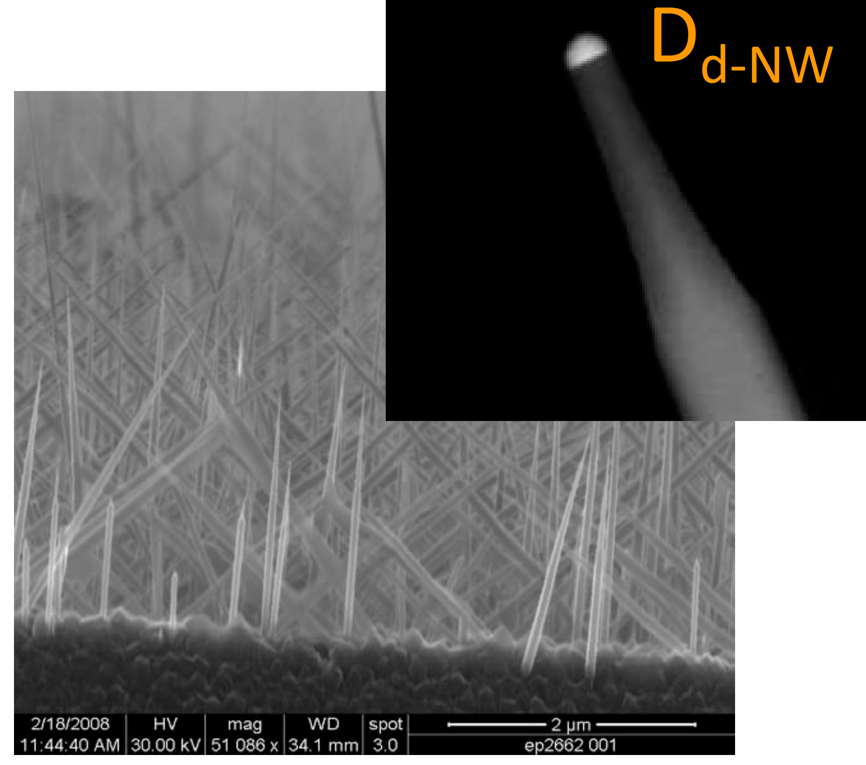


$CD_{NW} < 35$ nm for InP/Si

Chuang et al, Appl. Phys. Lett. 90, 043115 (2007)

INL results for InP NWs/Si with Au-In droplets

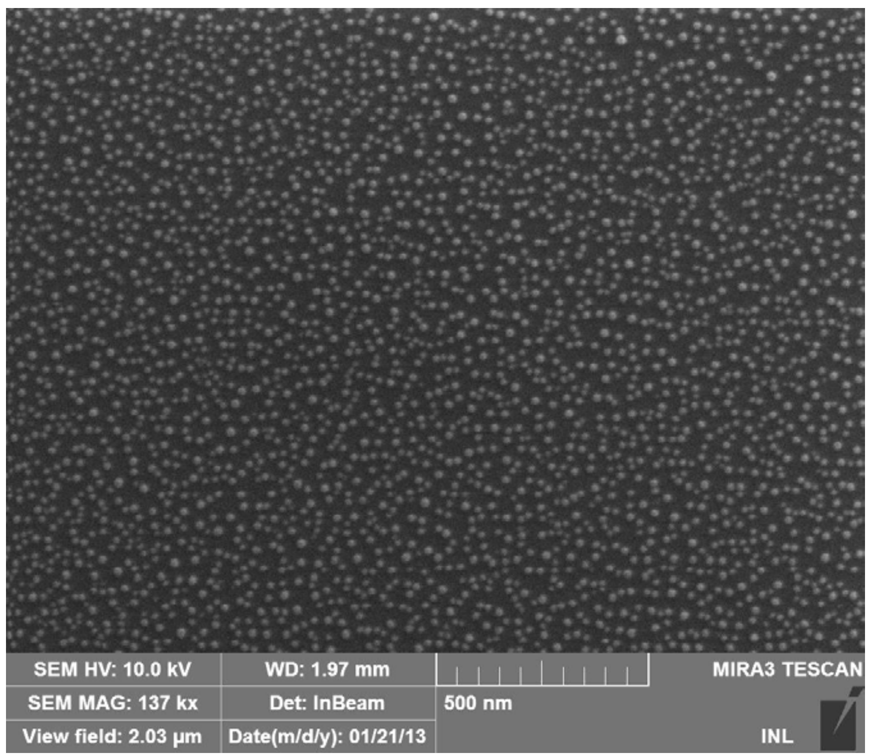
$D_{d\text{-}NW} < 33$ nm



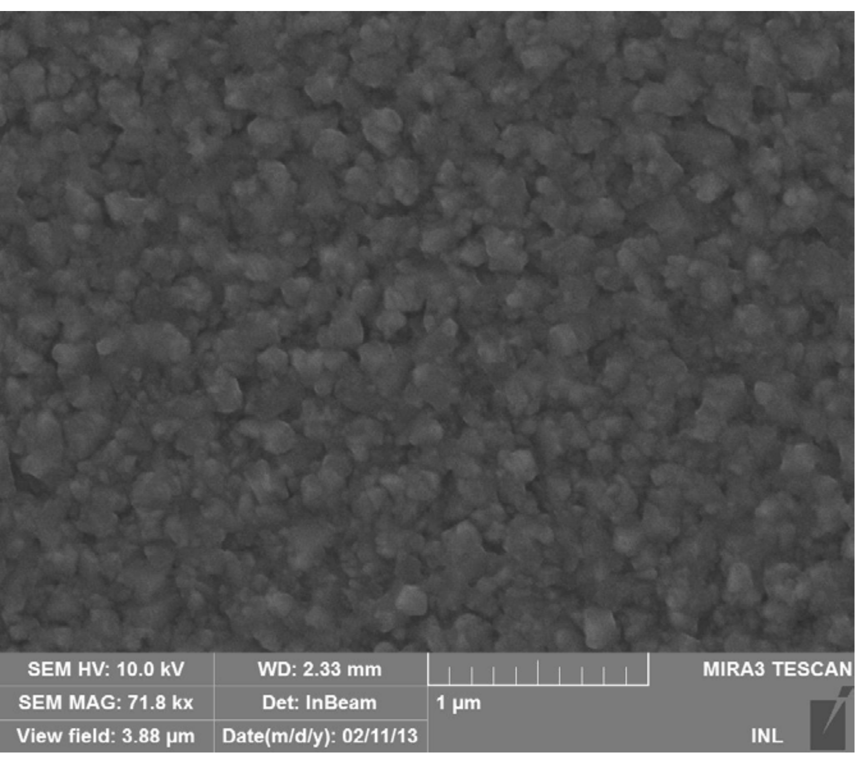
Naji et al, Appl. Phys. Lett. , to be published, 2013

Aim: In $D_{droplets}$ < 30 nm

Formation of In droplets at 380°C



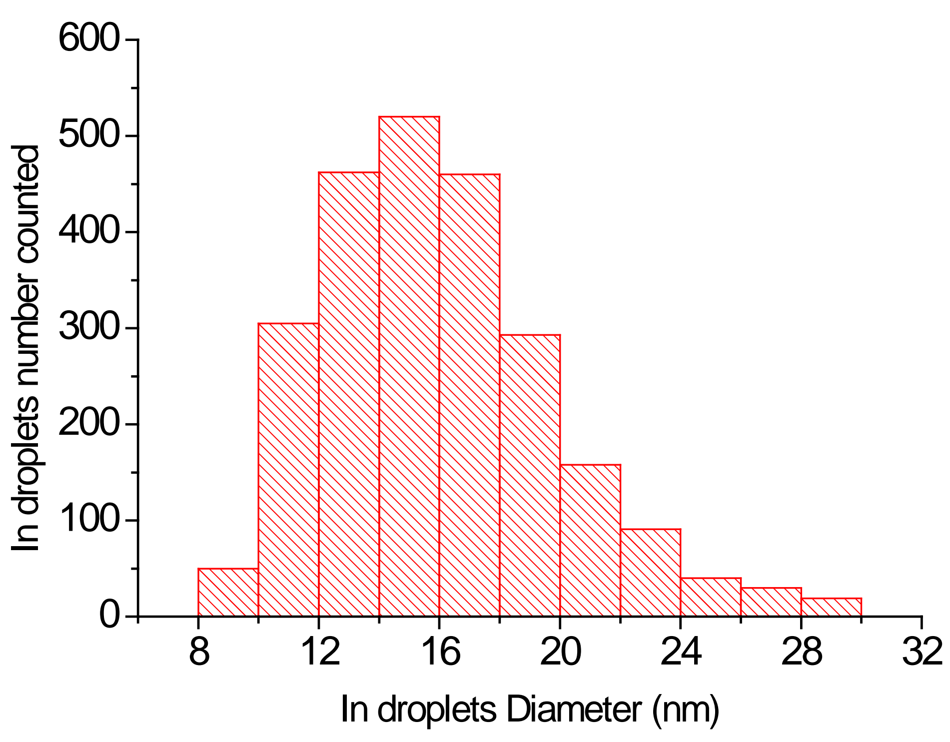
Growth of InP at 380°C



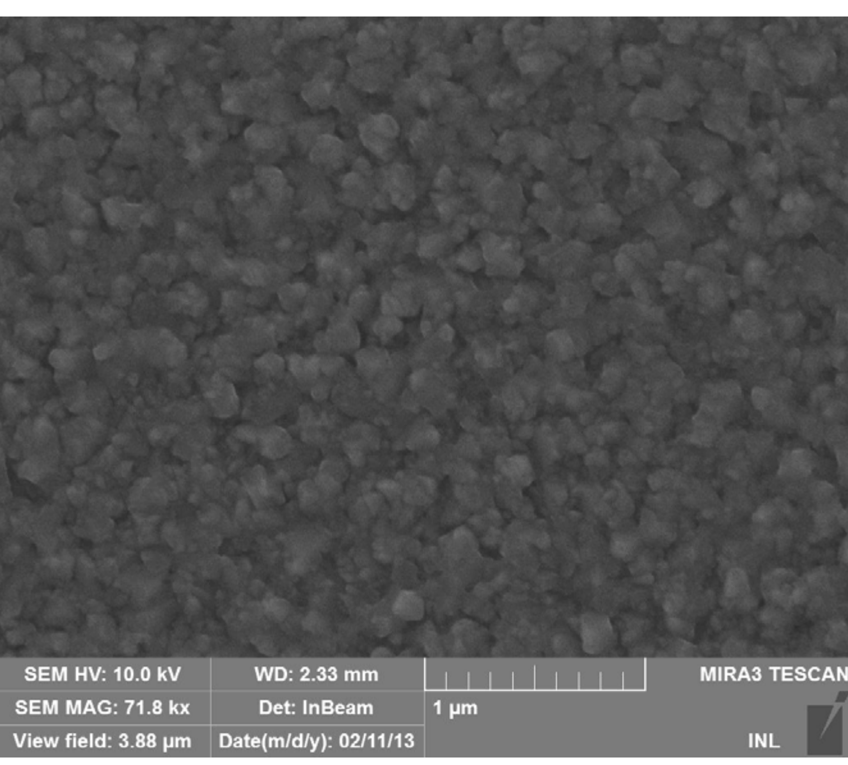
No NWs Growth

Aim: In $D_{droplets}$ < 30 nm

Formation of In droplets at 380°C



Growth of InP at 380°C



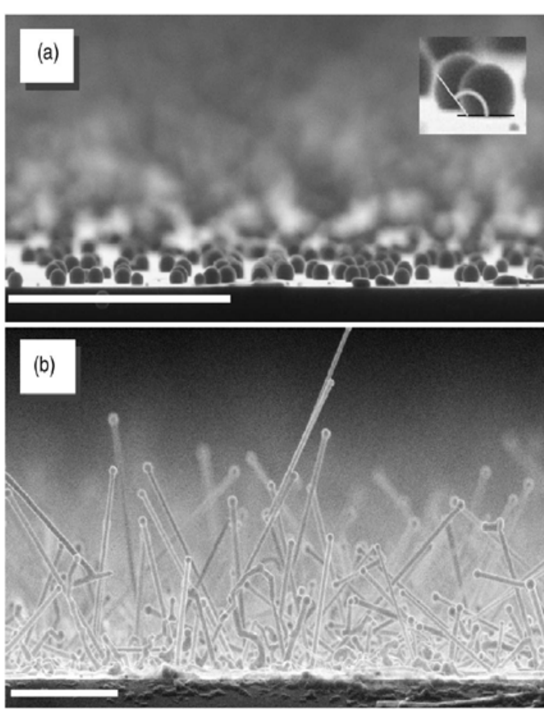
No NWs Growth

Growth study with In $D_{droplets} < 30$ nm

T_g / V/III	300°C	340°C	380°C	420°C	460°C
30					
20					
10					
5					

NO GROWTH OF NWs

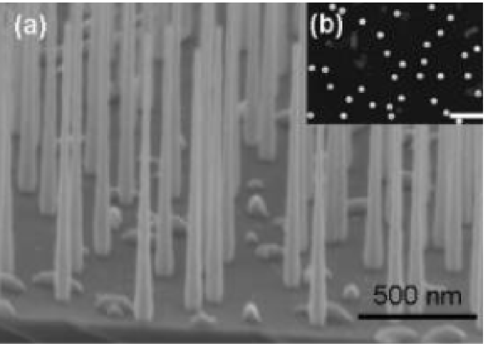
Reported works: Focus on In droplet diameter

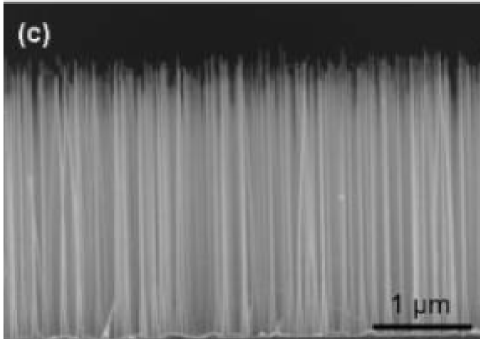


InP NWs on Si(111)

D = 55-90 nm

Mattila et al, APL 89, 063119 (2006)





InP NWs on Si(111)

D = 25-50 nm

Gao et al, Nano Lett., 9, 2223 (2009)

Specific study on In droplet diameter

What

Aim to $D_{limit} \geq 25$ nm

How

$D = f(v, N_{ML}, T)$

In deposition rate (ML/s)

N_{ML} deposited In

Substrate temperature

Which

Substrates

Si(111)

SiO_2
Si(111)

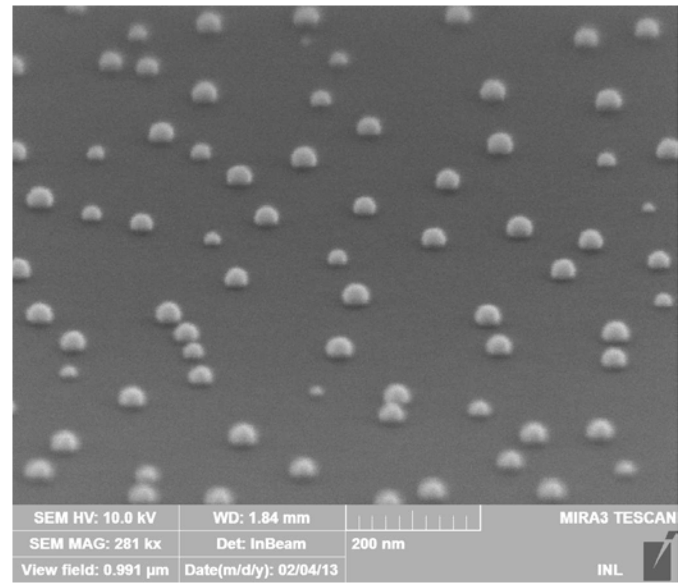
Si(001)

SiO_2
Si(001)

Self-catalysis with In droplets

- Au-free
- Indium element of the InP nanowire
- Indium not miscible in Silicon

T=400°C
0.2 ML/s
6 In ML



Weight Percent Indium

Temperature °C

Atomic Percent Indium

Si

In

L

(Si)

(In)

1414°C

156.63°C M.P.

99.996

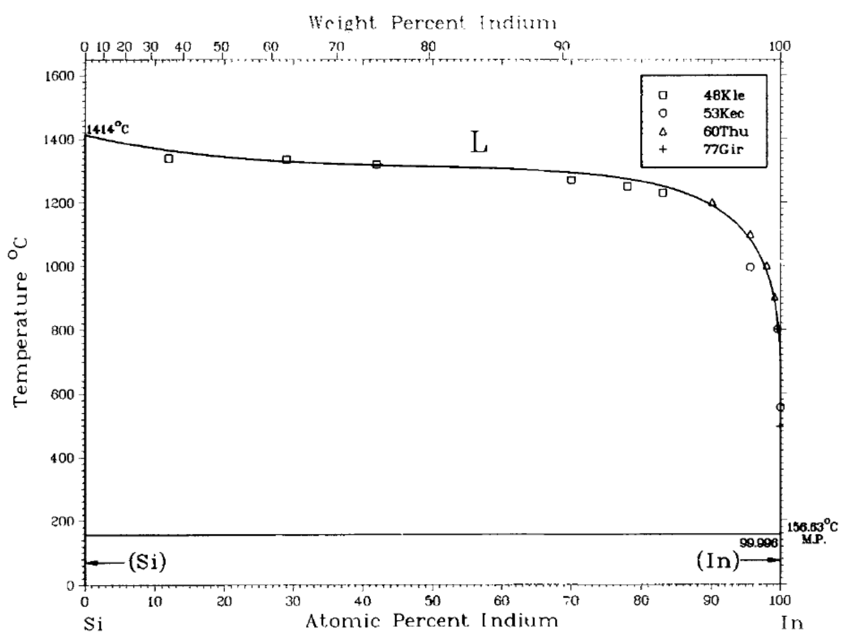
48Kle
53Kec
60Thu
77Gir

R. W. Olesinski, N. Kanani, and G. J. Abbaschian, 1985.

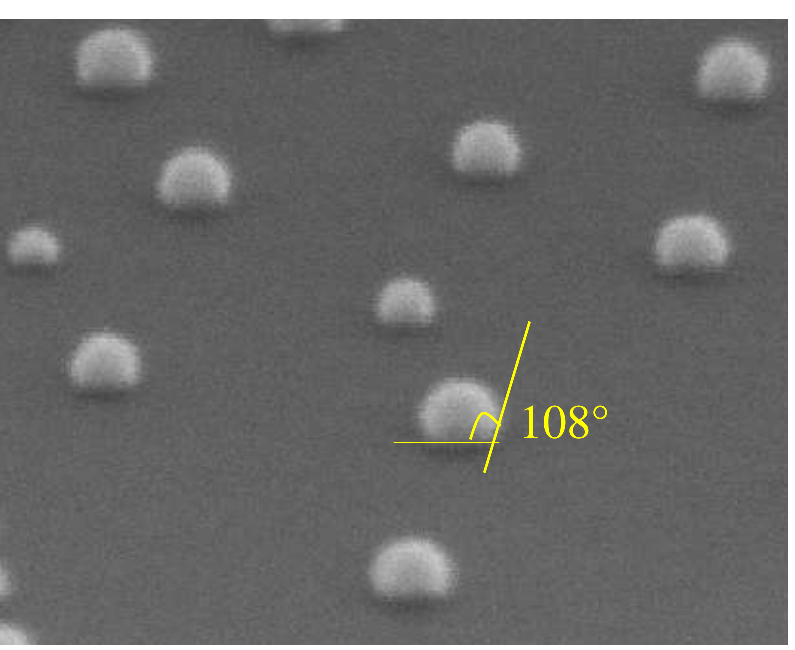
No In-Si alloy

Self-catalysis with In droplets

- Au-free
- Indium element of the InP nanowire
- Indium not miscible in Silicon



R. W. Olesinski, N. Kanani, and G. J. Abbaschian, 1985.



No In-Si alloy

Wetting angle : $90° < \theta < 130°$

Influence of In deposition rate v (ML/s)

T = 380°C, N = 6 ML, on Si(111) oxide free

Low rate 0.2 ML/s

Influence of N_{ML} deposited In

v = 0.2 ML/s , T = 380°C on Si(111) oxide free

diameter
density

Diameter (nm)
0 10 20 30 40 50 60

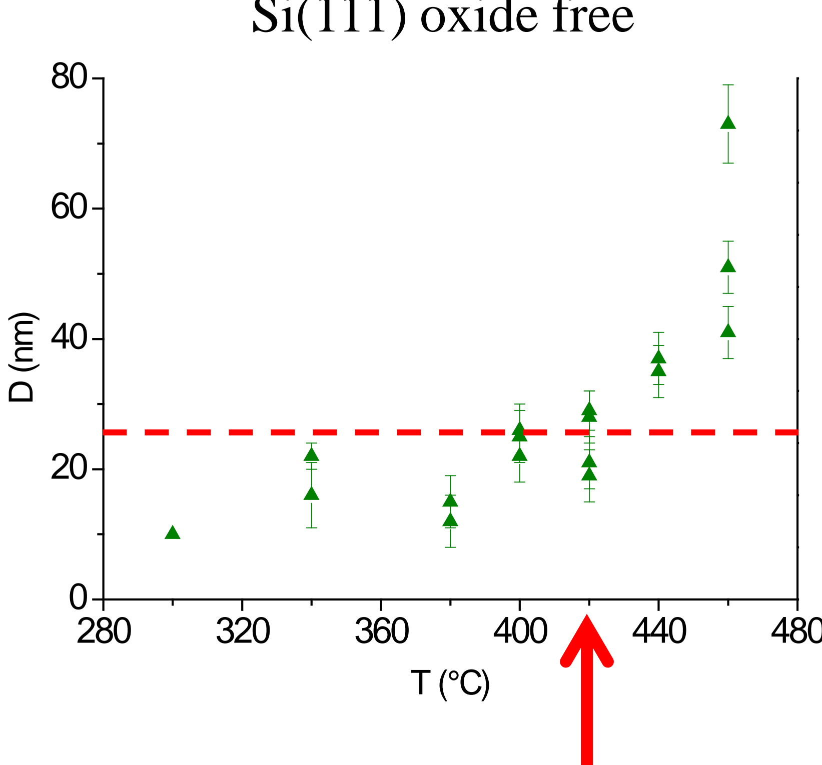
Density (/µm²)
100 1000

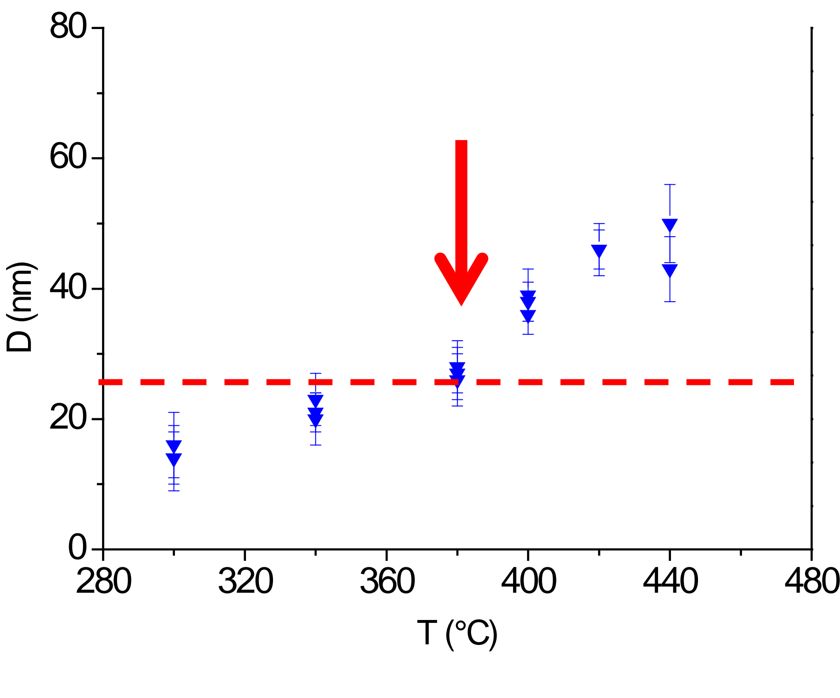
e In (ML)
1 2 3 4 5 6

$N_{ML} \geq 4$ ML

Influence of substrate temperature T (°C) on Si(111)

N_{ML} = 6 ML , v = 0.2 ML/sec





T ≥ 420°C for D > 25 nm

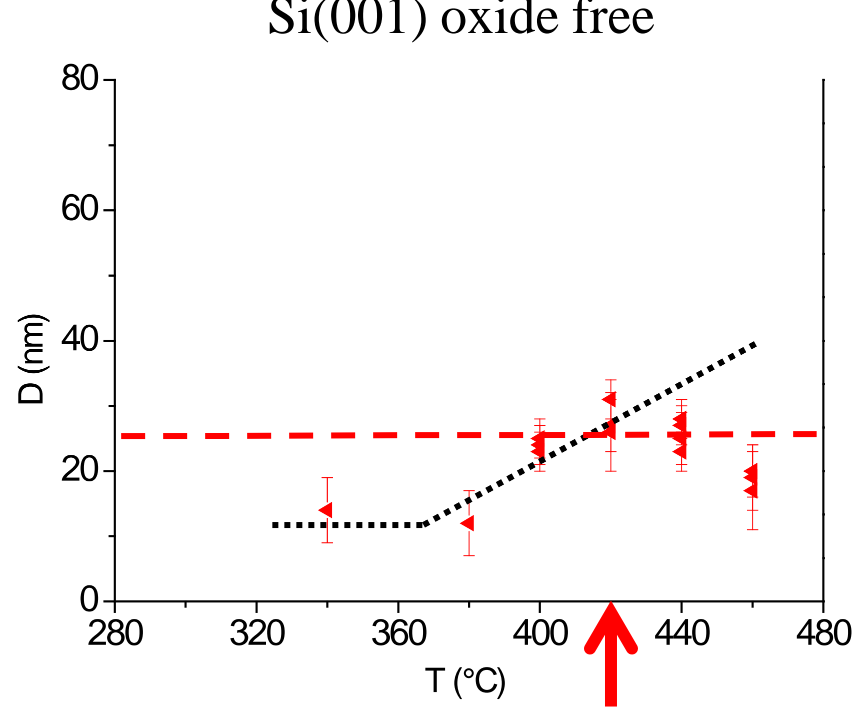
T ≥ 380°C

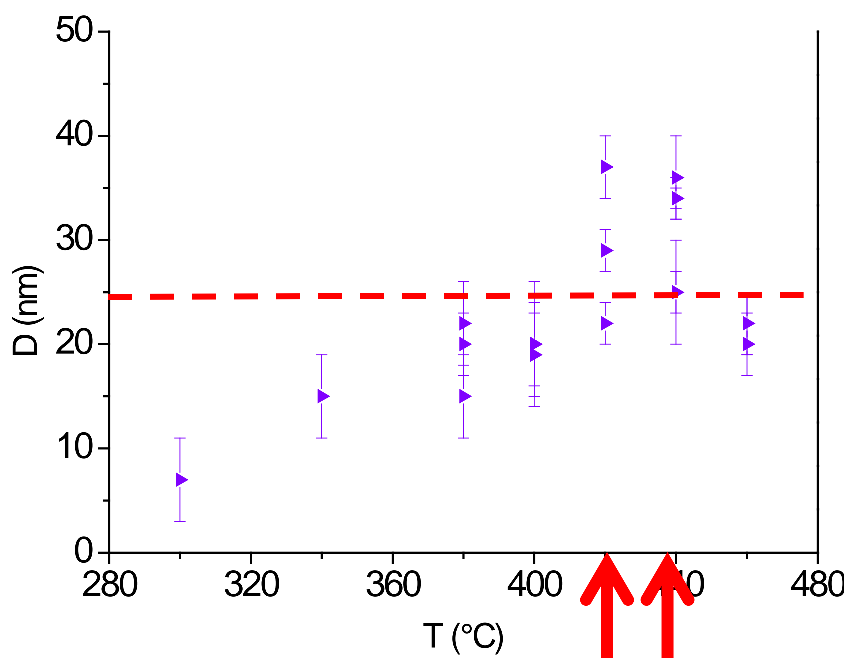
Stage at T ≥ 420°C

Influence of substrate temperature T (°C) on Si(001)

N_{ML} = 6 ML , v = 0.2 ML/sec

Si(001) oxide free





T=420°C

D decrease at T > 420°C

Desorption of In

T ≥ 420-440°C

Same behaviour at T> 440°C

Influence of substrate temperature T (°C) on Si(001)

$N_{ML} = 6$ ML , v = 0.2 ML/sec

Si(001) oxide free

V_{exp} Si(001) BOE
d Si(001) BOE

Experimental volum of indium droplets V_{exp} (10^6 nm³/µm²)
Density d of indium droplets (/µm²)
Sample temperature T (°C)

T=420°C
D decrease at T > 420°C
Desorption of In

Si(001) with natural oxide

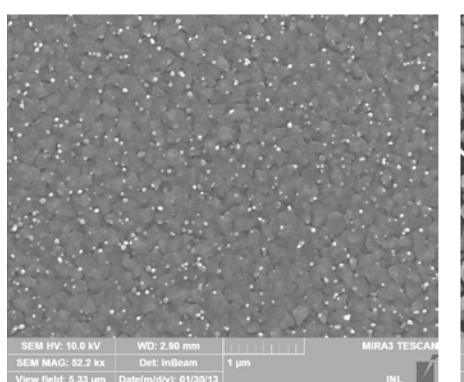
D (nm)
T (°C)

T ≥ 420-440°C
Same behaviour at T> 440°C

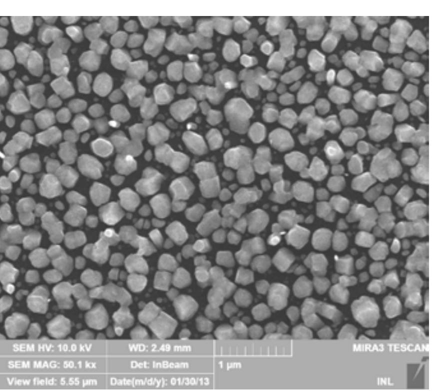
NWs Growth with $D_{droplets} \geq 25$ nm

$T_g = 380°C$, V/III = 20, $t_g = 5$ min

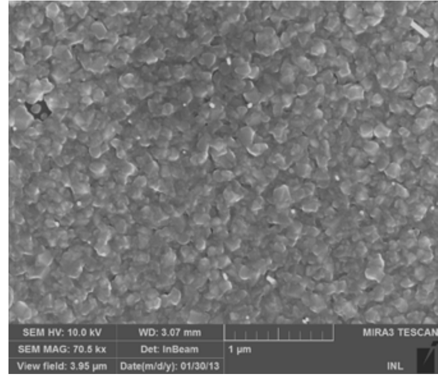
$T_{droplets} = 400°C$



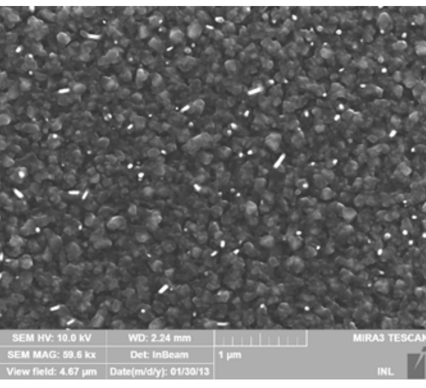
Si(111) oxide free
d ~ 8-30/µm²



Si(111) nat. oxide
d ~ 0.34-1.6/µm²

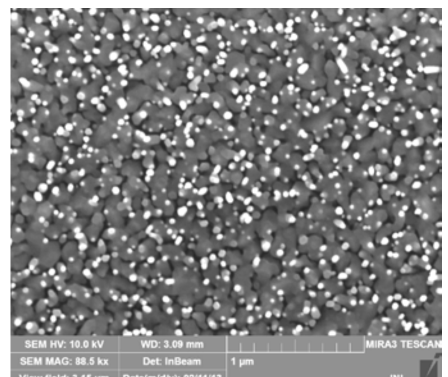


Si(001) oxide free
d ~ 1.9-6/µm²

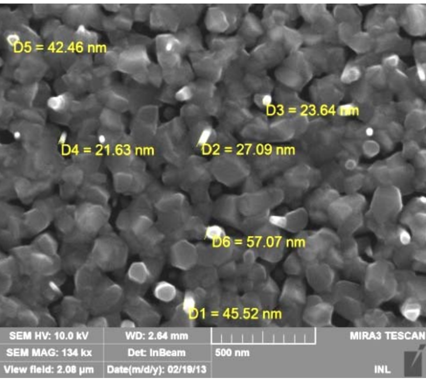


Si(001) nat. oxide
d ~ 1.37-2.17/µm²

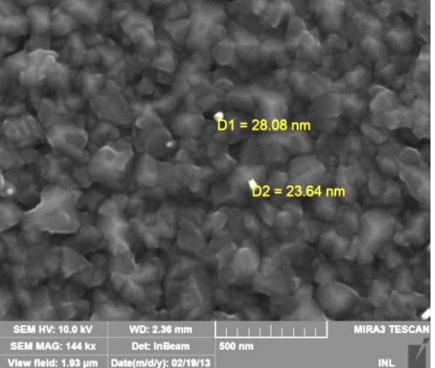
$T_{droplets} = 420°C$



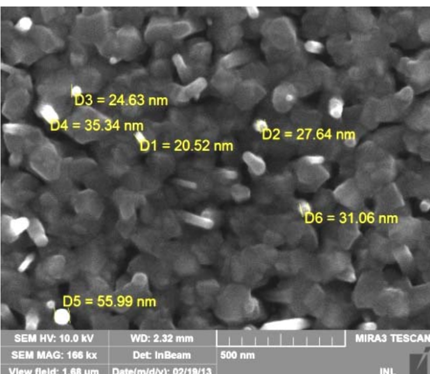
Si(111) oxide free
d ~ 100/µm²



Si(111) nat. oxide
d ~ 3-7/µm²



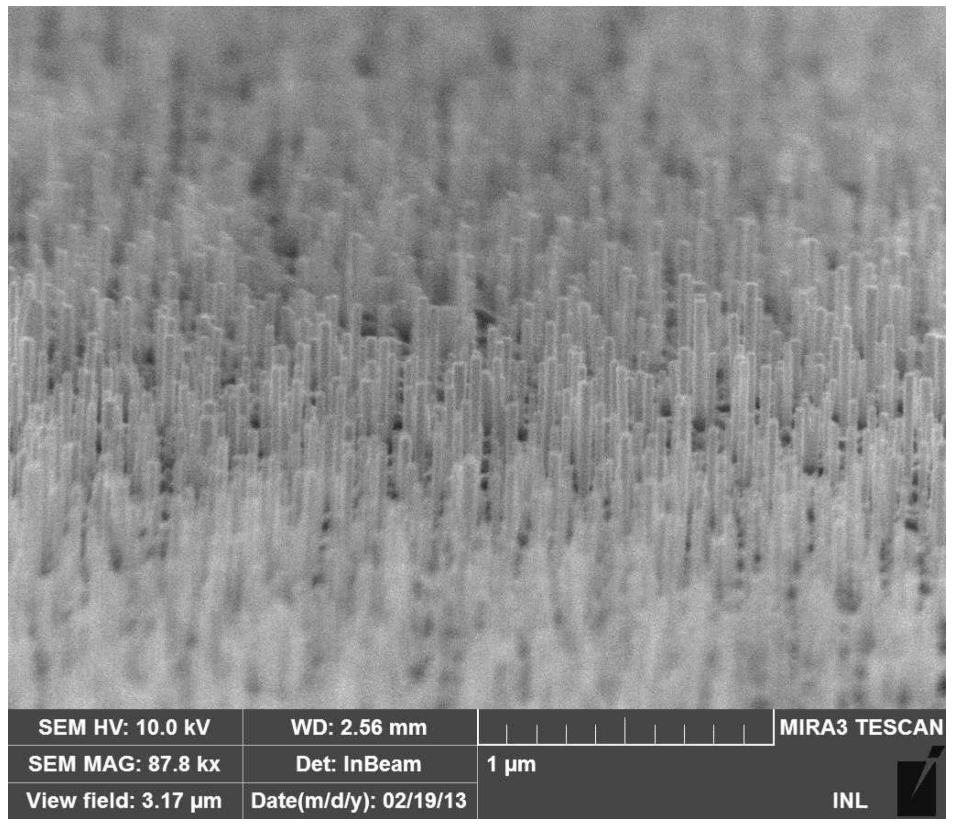
Si(001) oxide free
d ~ 0.73-1.14/µm²



Si(001) nat. oxide
d ~ 9-11/µm²

InP NWs on Si(111) oxide free at T_g=380°C

$T_{droplets}$= 420°C, Tg=380°C, V/III=20, t_g = 5 min



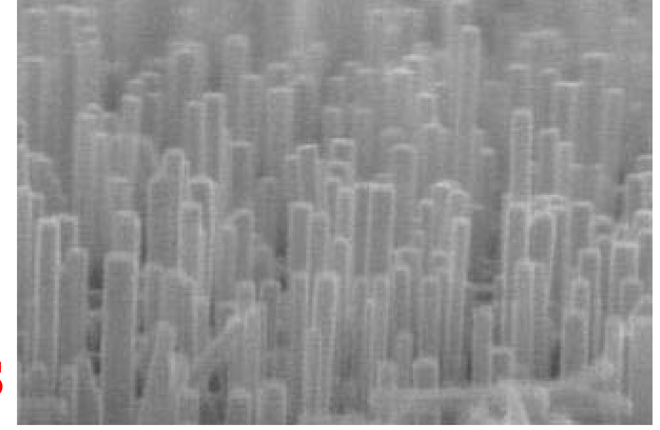
d_{NWs} ~ 100 / µm²

Very uniform in D

L < 300 nm

dL /dt = 50 nm/min

No droplets at the tip

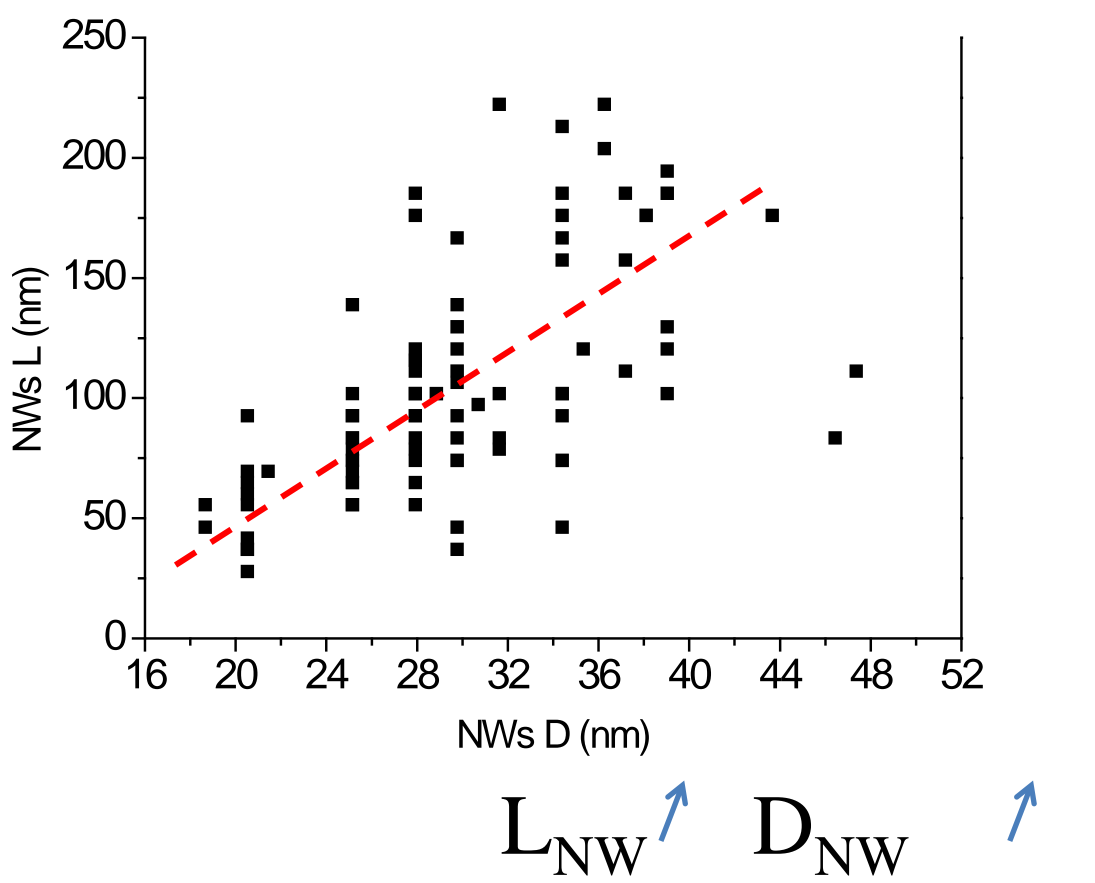


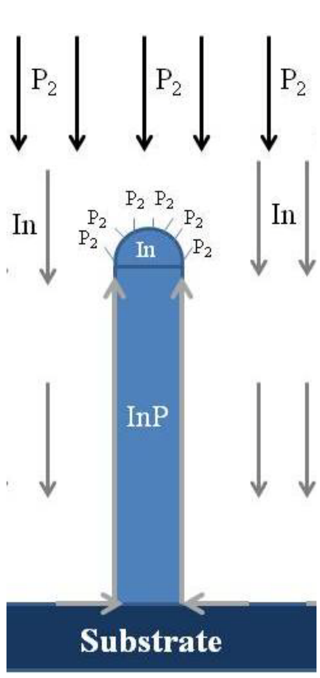
Consumption of the In droplets
Due to cooling under phosphorus

InP NWs on Si(111) oxide free at T_g=380°C

$T_{droplets}$= 420°C

Tg=380°C, V/III=20, t_g = 5 min





L_{NW} ↗ D_{NW} ↗

NW growth non-induced by surface diffusion as for VLS-CVD

Structural properties of InP/Si(111) NWs at T_g = 380°C

$T_{droplets}$= 420°C

V/III=20, t_g = 5 min

FFT

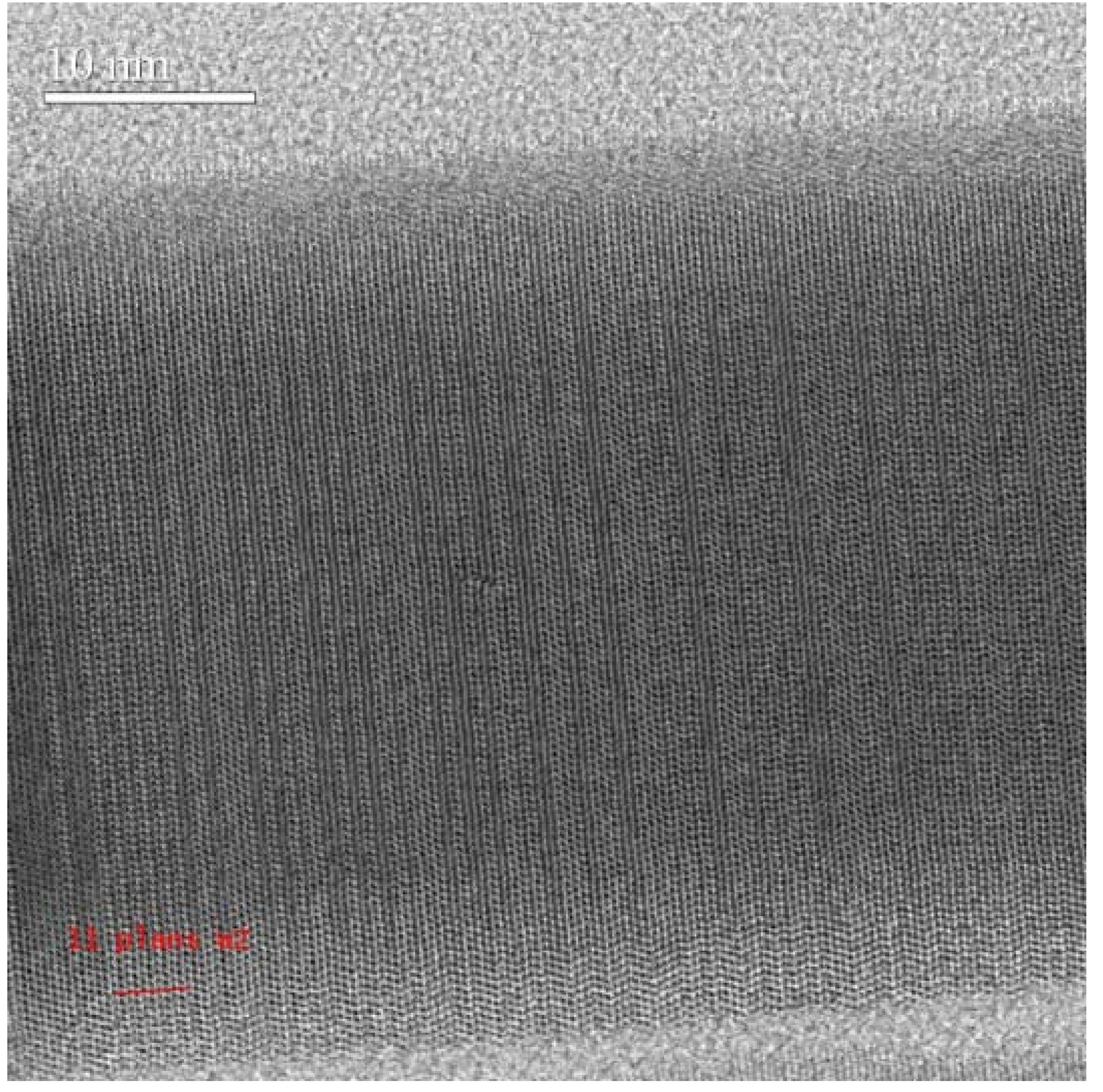
ZB NWs

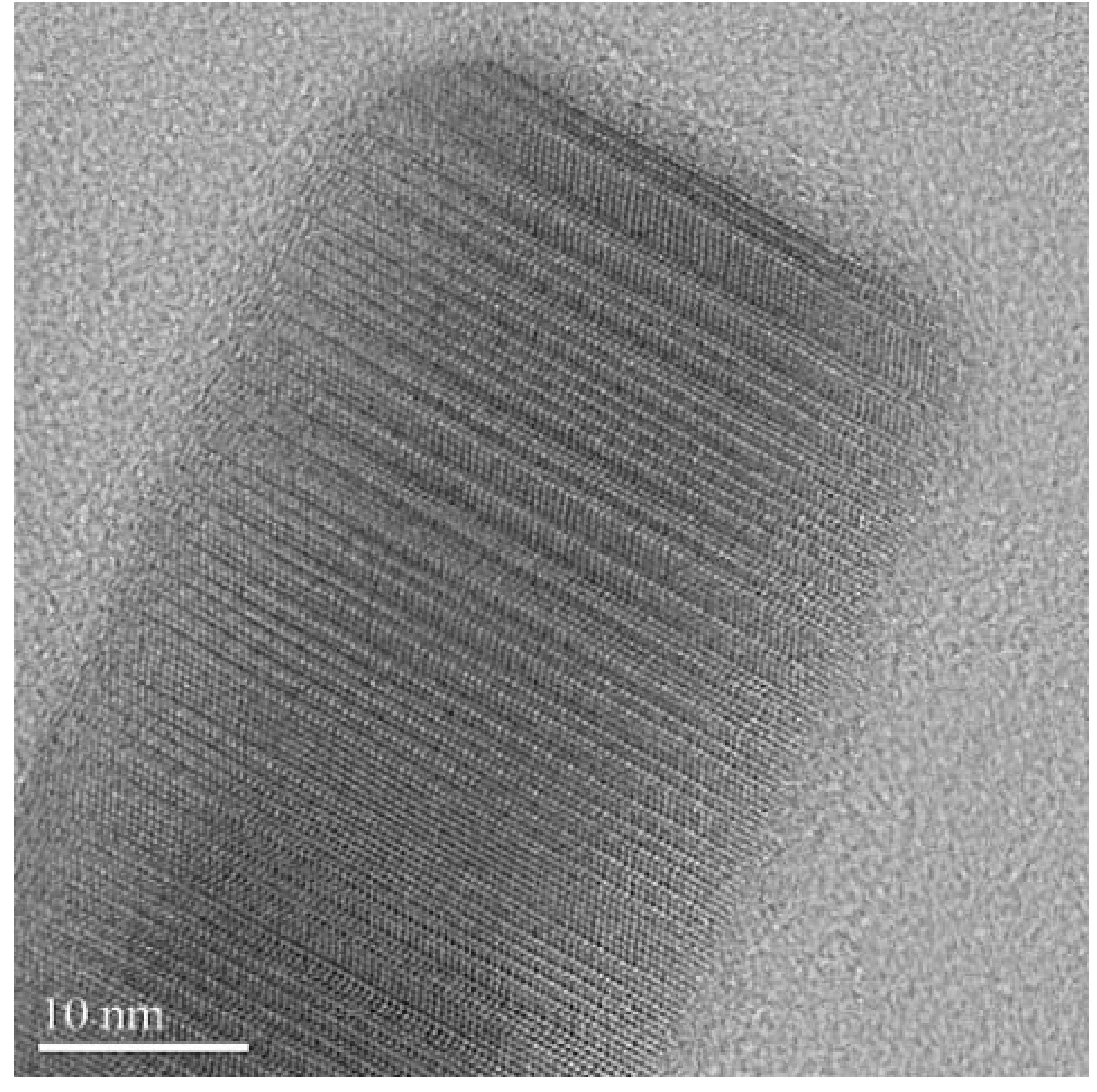
High twin density

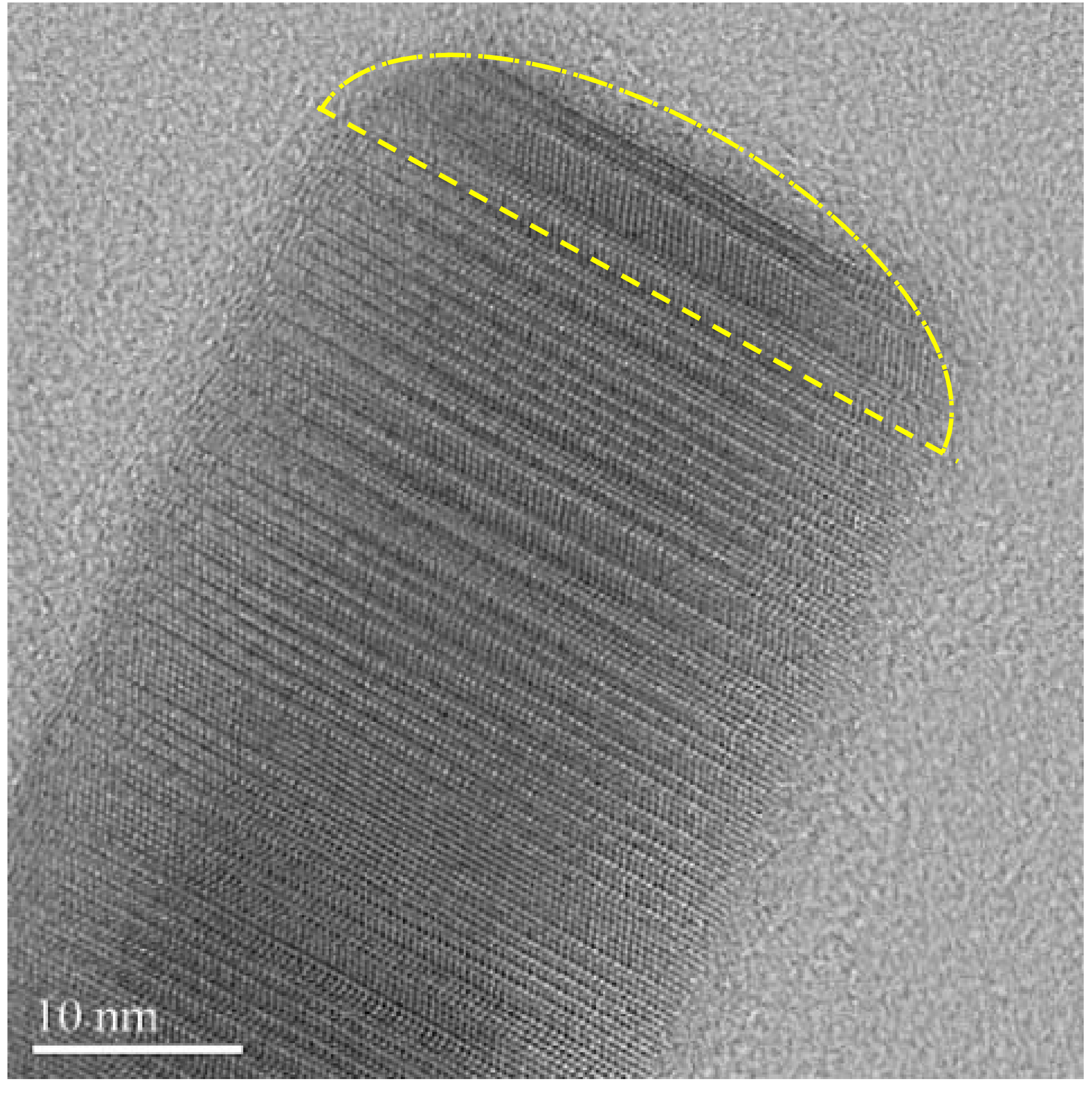
FFT

TEM: G. Patriarche-LPN

Wz segment


10 nm


10 nm


10 nm

Optical properties of InP/Si(111) NWs at $T_g = 380°C$

Weak peak intensity

InP ZB

InP WZ

E = 1.4375 eV

Slighly > E_{InPZB}

~100 ps

~660 ps

~400 ps

400 ps: short decay time for InP ZB ?

100 ps: Non-radiative recombination

Surface recombination due to surface defect?

R. Anufriev and N. Chauvin

Conclusion and Perspective

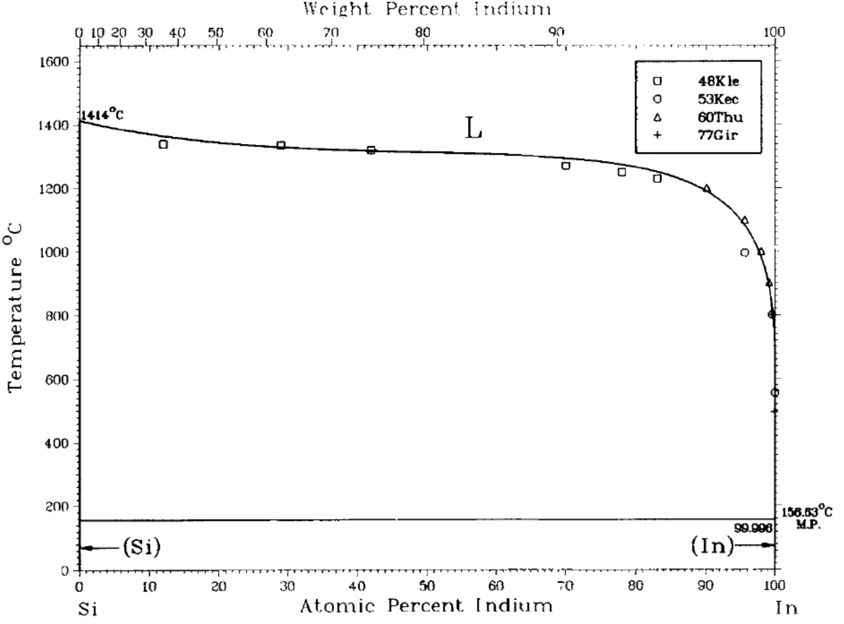
- **We know how to Self-catalyzed growth of InP/Si(111) by MBE with well adapted indium droplets diameter**

Perspectives:

- Optimization of growth conditions
- Pure ZB InP NWs
- Verticality on Si(001)
- Selective growth on structured Si surface

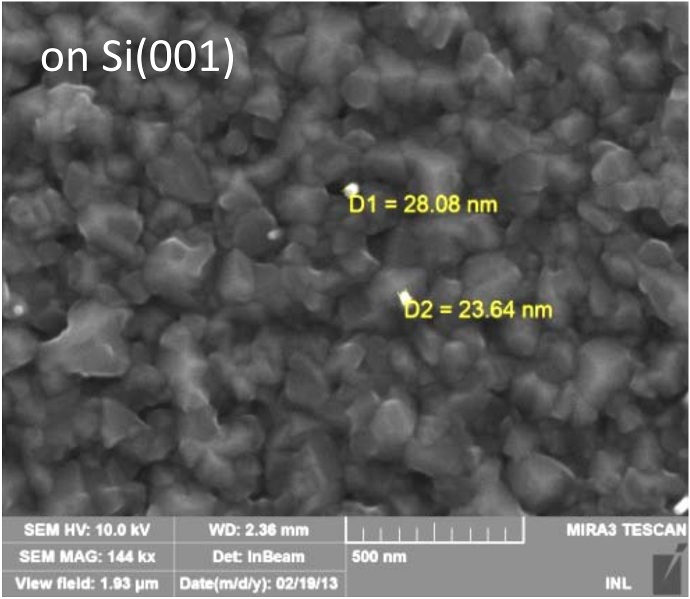
Self-catalysis with In droplets

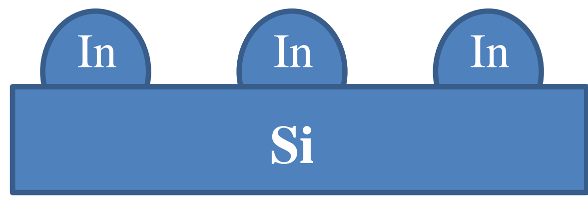
- Au-free
- Indium element of the InP NWs
- Indium not miscible in Silicon



R. W. Olesinski, N. Kanani, and G. J. Abbaschian, 1985.

No In-Si alloy





No digging of the Si substrate:
Verticality on Si001?

APPLIED PHYSICS LETTERS 100, 053107 (2012)

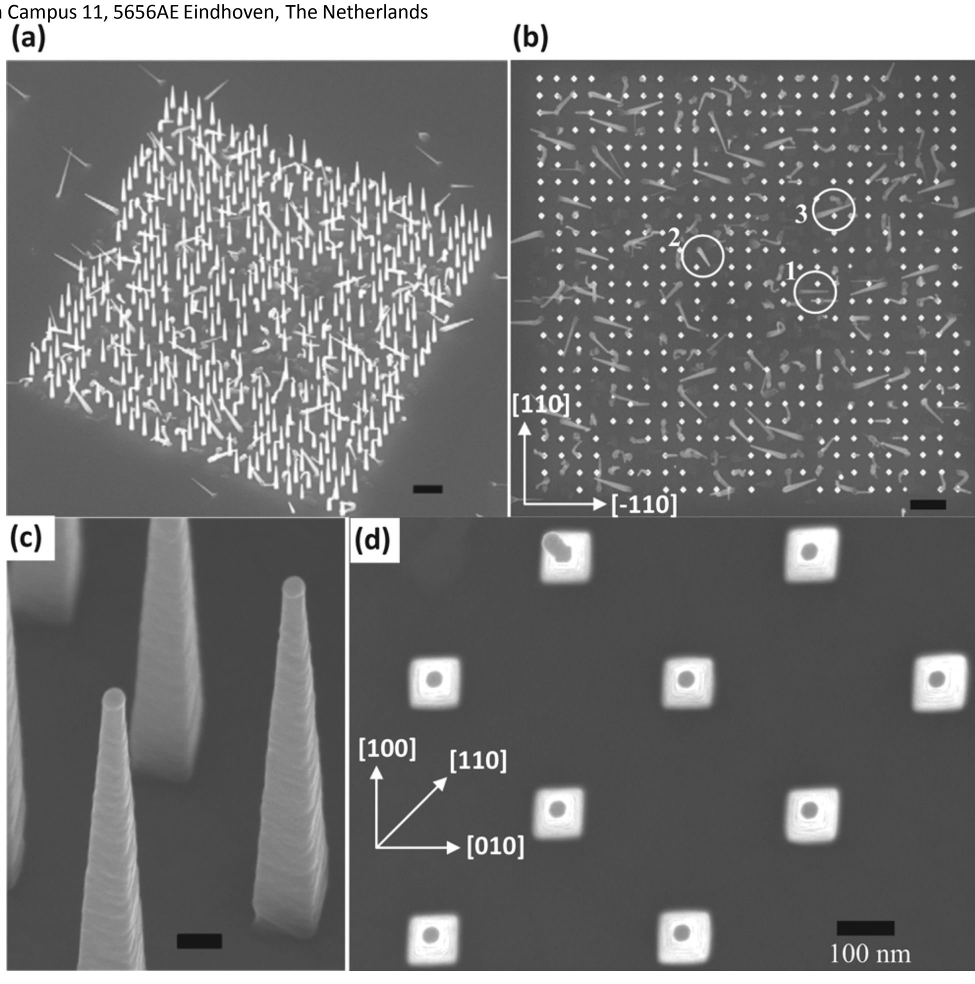
Position-controlled [100] InP nanowire arrays

Jia Wang,1 Se´bastien Plissard,1 Moı¨ra Hocevar,2 Thuy T. T. Vu,1 Tilman Zehender,1
George G. W. Immink,3 Marcel A. Verheijen,1,3 Jos Haverkort,1
and Erik P. A. M. Bakkers1,2,a)

1Department of Applied Physics, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands
2Kavli Institute of Nanoscience, Delft University of Technology, 2628CJ Delft, The Netherlands
3Philips Innovation Services Eindhoven, High Tech Campus 11, 5656AE Eindhoven, The Netherlands

In this work, we report on the growth of [100] ZB InP NWs by the vapor-liquid-solid (VLS) growth mechanism21 catalyzed by Au and using low-pressure (50 mbar) metalorganic vapor phase epitaxy (MOVPE) on Sn-doped InP (100) substrates;

À faire sur Si(001)
Pour l'INL



SEM images of as-grown InP NW arrays on a InP (100) substrate with Au diameters (DAu)=50 nm, pitch=500 nm,

Feuille de route projet INSCOOP- Michel Gendry

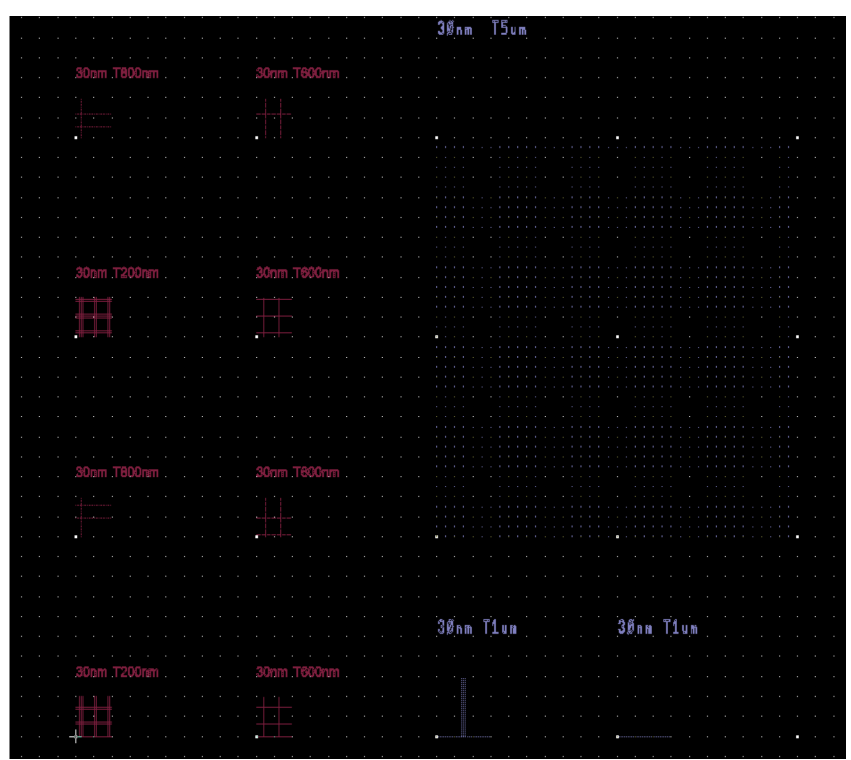
Echantillon : INSCOOP06022013-1

Substrat Si(001)

Résine PMMA 4%

Litho électronique : réseaux de trous dans la résine (masque 30-50-70 nm) + dépôt 10 nm d'Au + lift-off.

Masque utilisé :



+ résine de découpe AZ1512 ….. NB : réseaux de plots dans les coins des échantillons

- à enlever avec acétone/alcool/soufflette N2g ……..puis plasma O2

NB : comme Pb de SB à l'INL, wafer retourné à Bassem le 19-02-2013 pour qu'il fasse cette manip !

Retour le 13-03-2013 : 10 échantillons nettoyés

BOE/H20/N2g

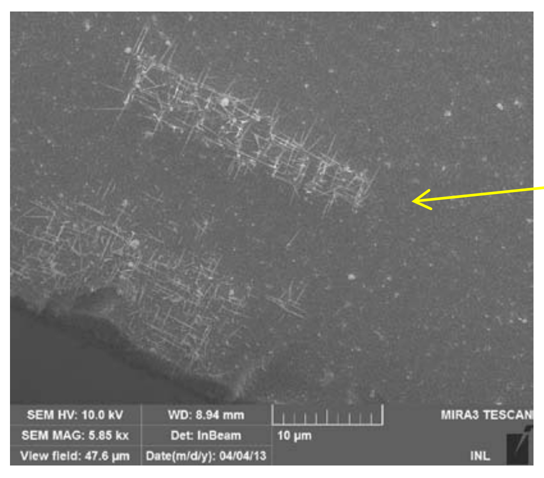
TT 600°C 5 mn + flux d'In (6ML)

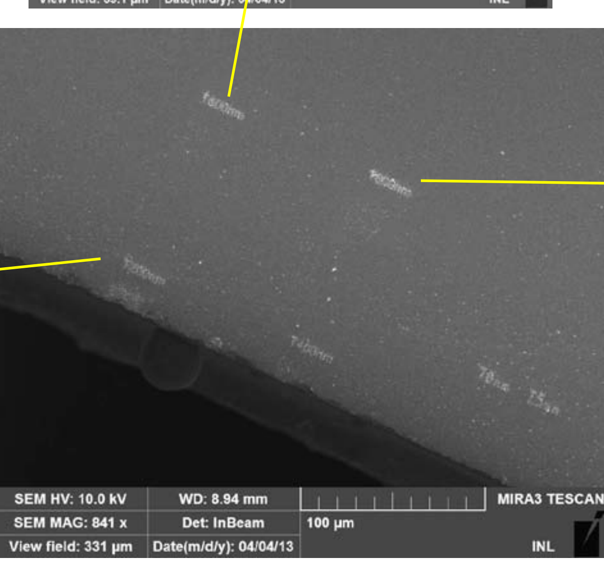
Croissance NFs à 380°C, V/III=20

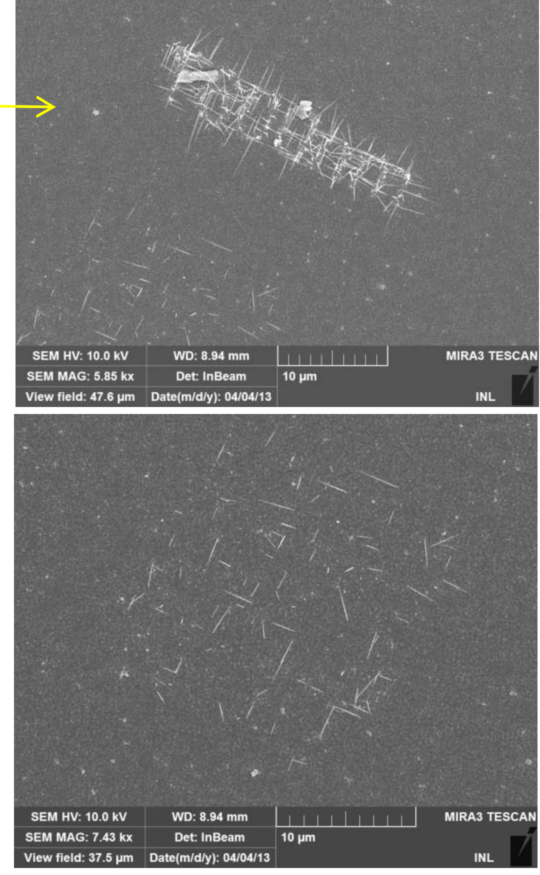
SEM HV: 10.0 kV
WD: 8.94 mm
MIRA3 TESCAN
SEM MAG: 7.12 kx
Det: InBeam
10 µm
View field: 39.1 µm
Date(m/d/y): 04/04/13
INL

T=600 nm?

T=800 nm?







Annexes

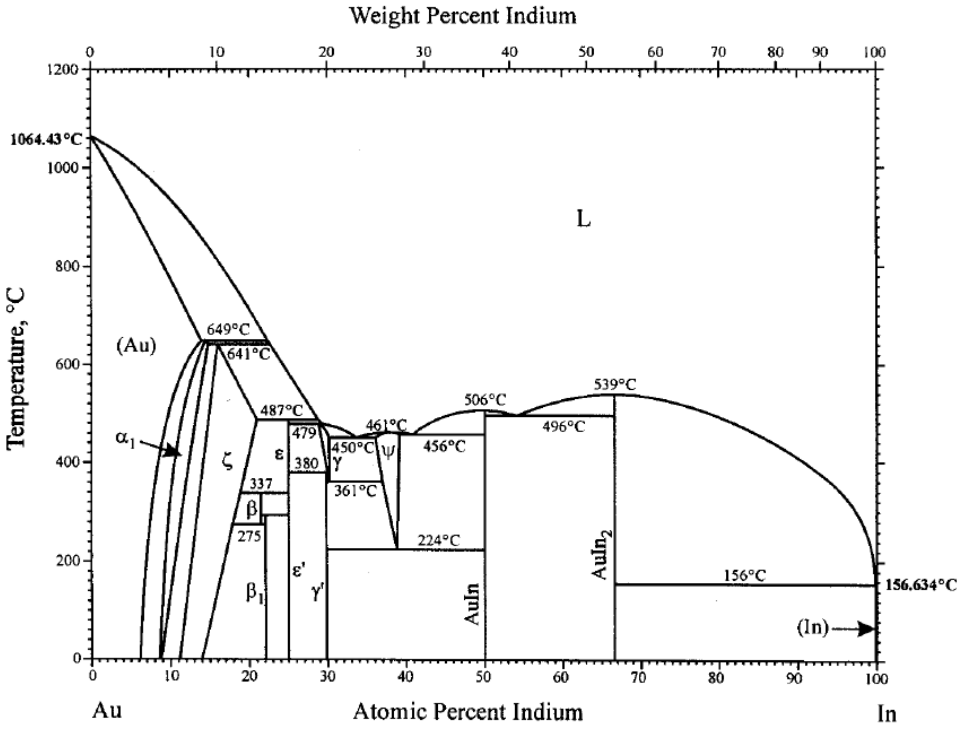
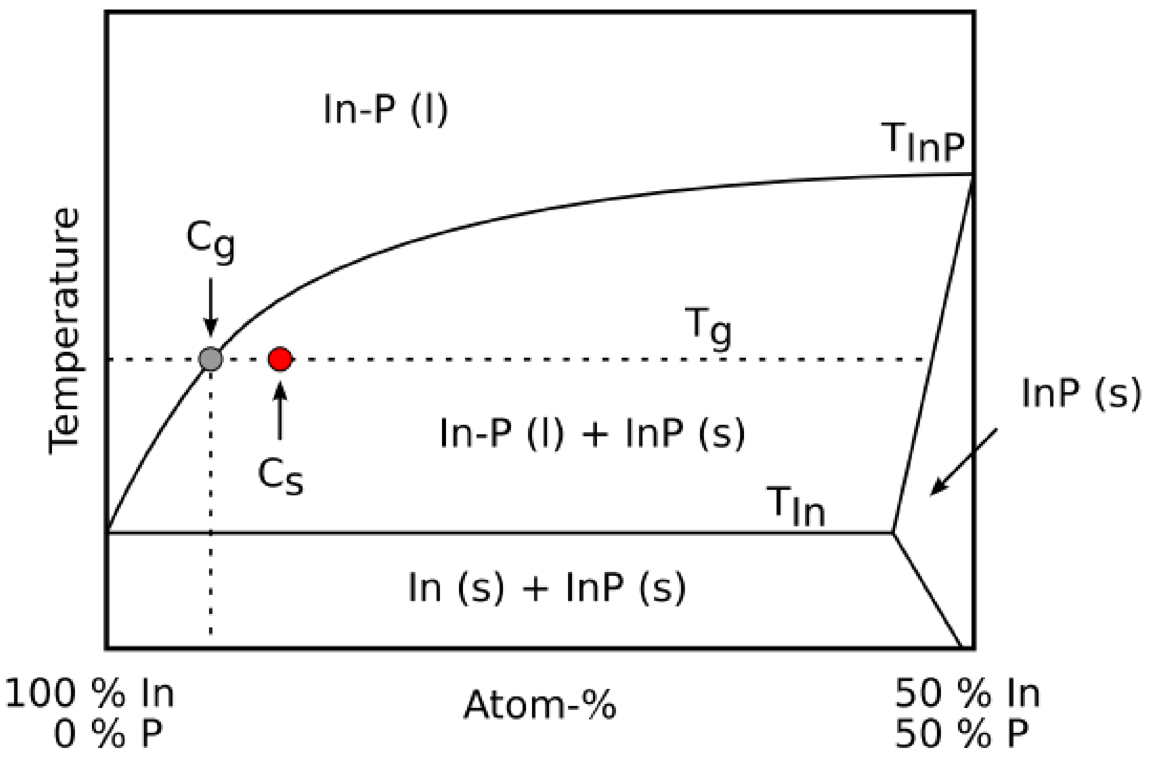
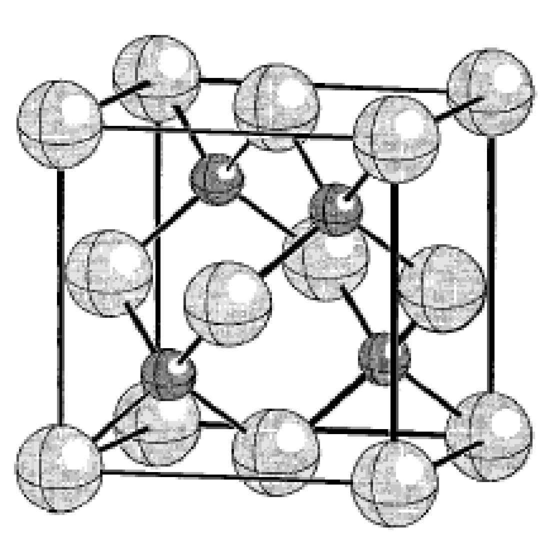


Fig. 1 Au-In phase diagram calculated by [2003Liu]

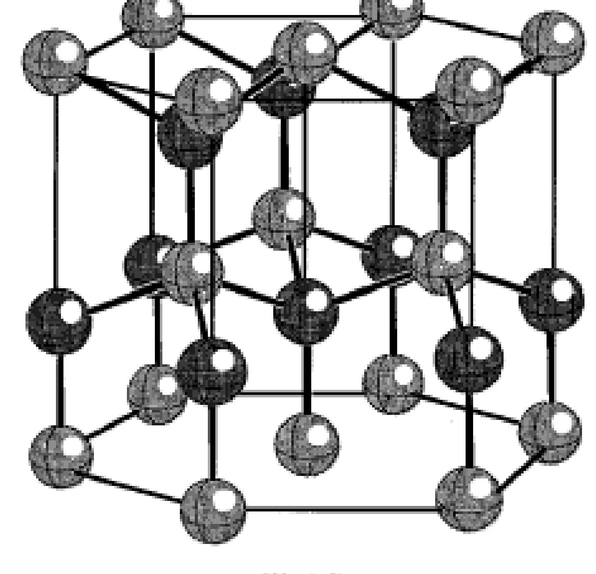

In-P (l)
T_{InP}
C_g
T_g
Temperature
InP (s)
In-P (l) + InP (s)
C_s
T_{In}
In (s) + InP (s)
100 % In
0 % P
Atom-%
50 % In
50 % P

Structure of III-V

a_{Si}=5.43 Å
a_{InP}=5.86 Å
E_{InP}=1.42 eV
E_{Si}=1.08 eV

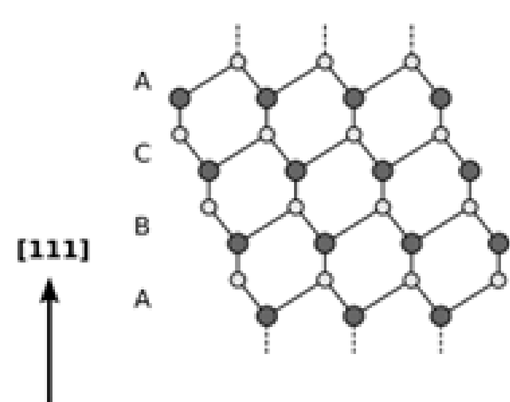


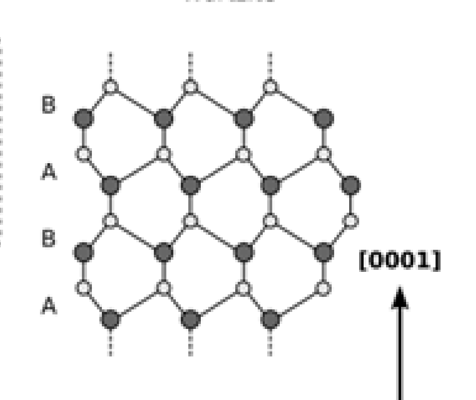
Zinc-blende

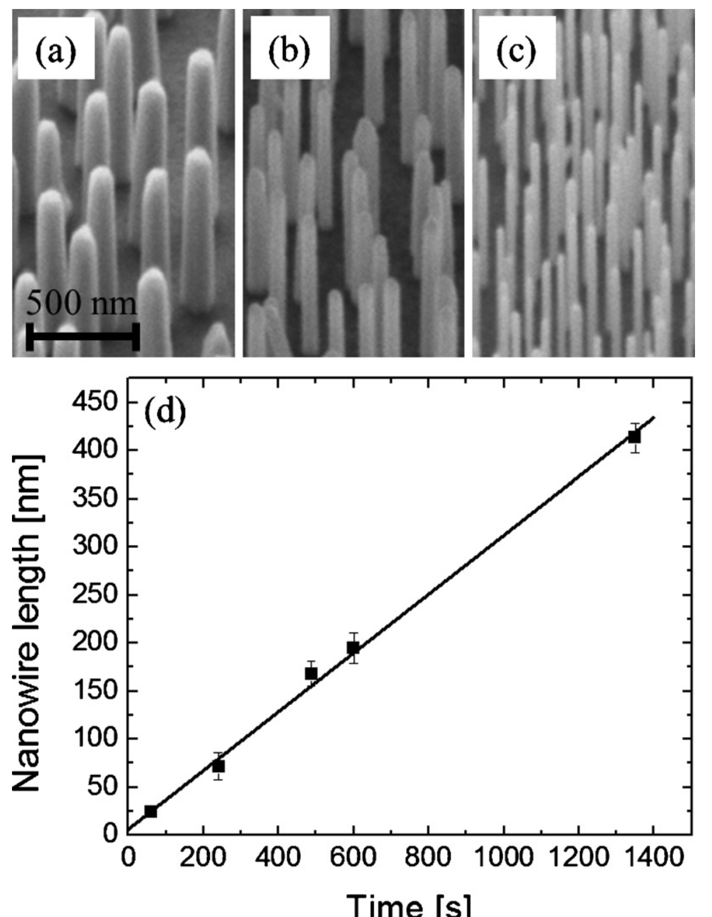


Wurtzite

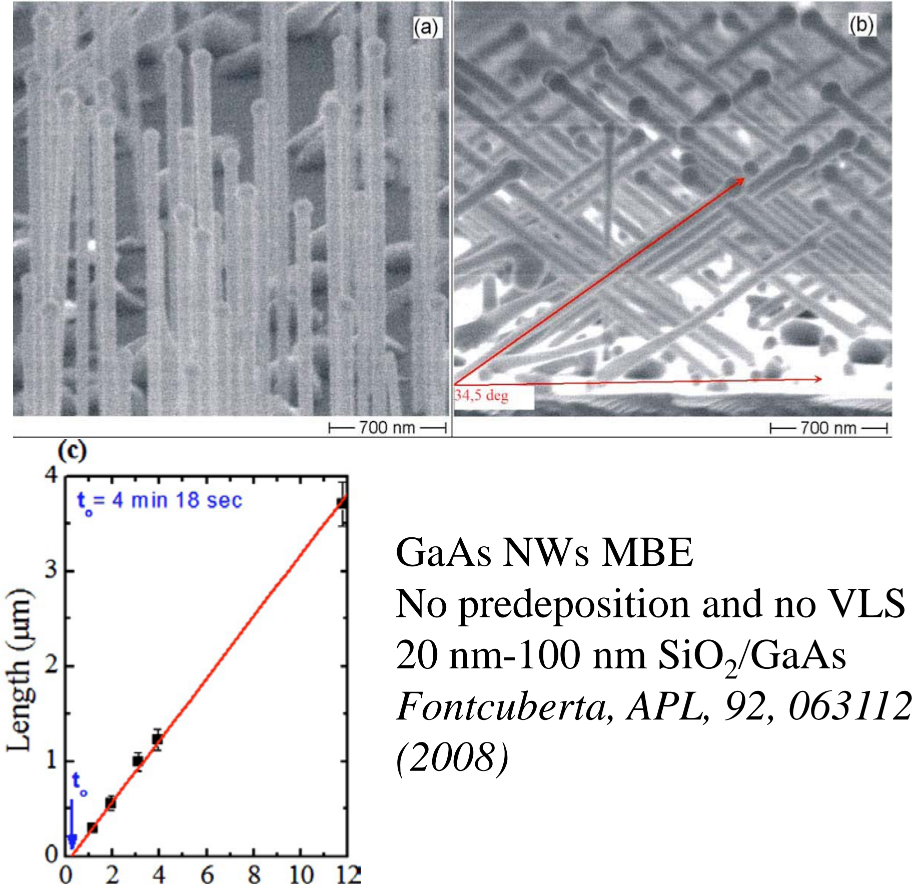
a_{InP}=4.054 Å
c_{InP}=6.625 Å
E_{InP}=1.49 eV







InAs NWs MBE
No predeposition and no VLS
SiOx/Si(111) with openings
Hirtenberger, APL, 98, 1231114 (2011)



GaAs NWs MBE
No predeposition and no VLS
20 nm-100 nm SiO_2/GaAs
Fontcuberta, APL, 92, 063112 (2008)