Diffusion réactive en microélectronique

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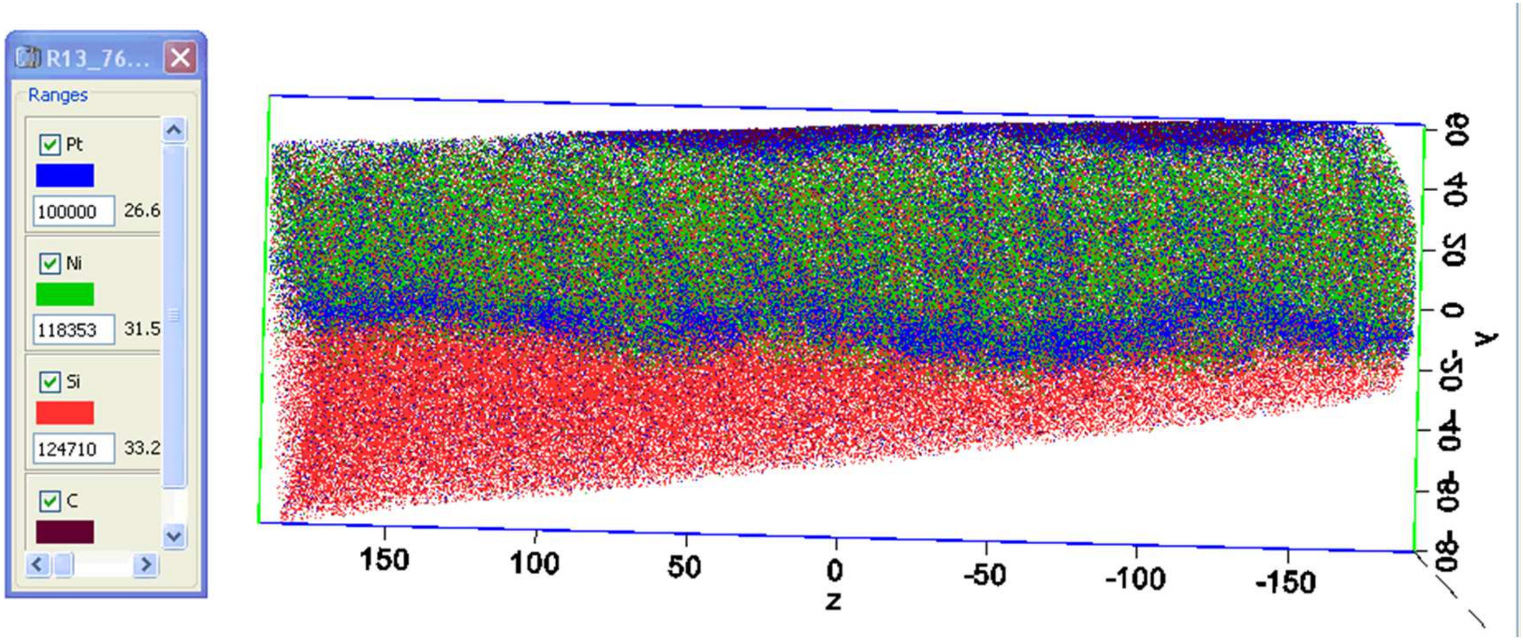

R13_76...

Ranges

☑ Pt 🟦 100000 26.6

☑ Ni 🟩 118353 31.5

☑ Si 🟥 124710 33.2

☑ C ■

Atom probe tomography of Ni(Pt) silicide on Si(100)

Acknowledgments

- **IM2NP :** C Bergman, M Bertoglio**, I Blum** , **A. Derafa**, M. Descoins, B Duployer, L Ehouarne, P Gas**, K. Hoummada, F. Nemouchi , F. Panciera, G. Tellouche,** A. Portavoce

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- **ATMEL :** R. Coppard

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  - ANR TAPAS
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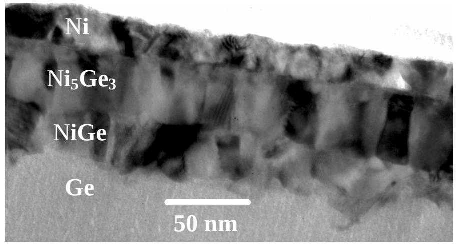
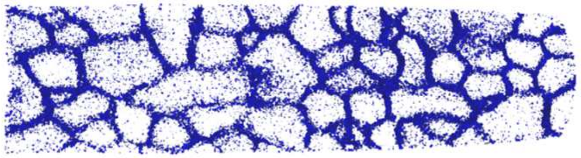
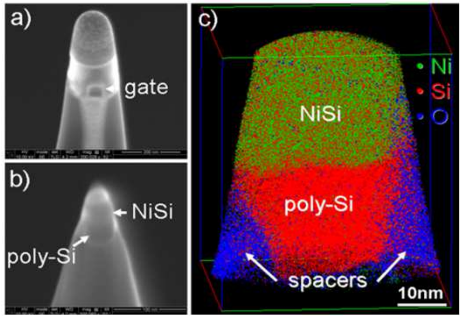
Reactive diffusion in microelectronics: outline



1. **Basis of reactive diffusion**
    a) Diffusion couple / thin films
    b) First stages : nucleation and lateral growth
    c) Deal & Grove law and silicides
    d) Sequential growth –simultaneous growth
    e) Role of grain boundaries



2. **Typical example : silicides in microelectronics**
    a) Contacts in microelectronics
    b) Analyses of transistors by atom probe
    c) Nucleation and alloy effect



3. **Challenges**
    a) Encroachment / transient phase
    b) Nucleation / texture / stress
    c) Doping / defects / dislocation / precipitation / redistribution
    d) Nanoelectronics

Bulk diffusion couple

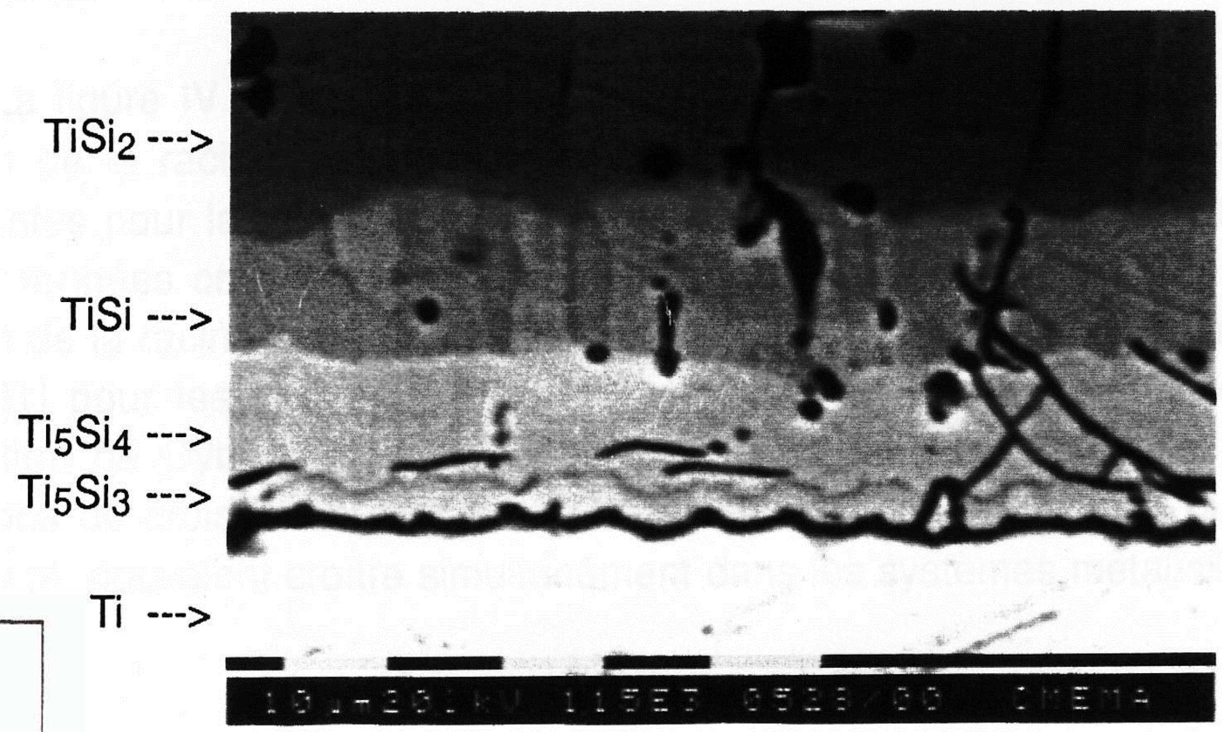
Two bulk materials in contact

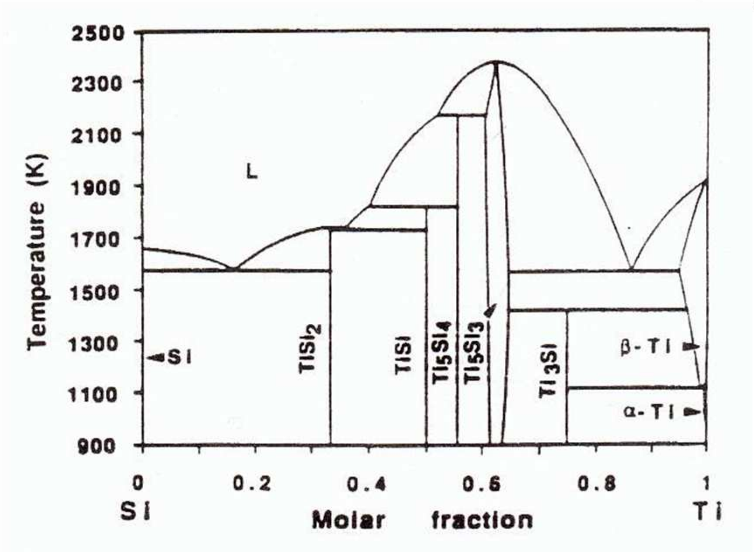
+ Heat treatment

+ Micrography

→ all the phases of the equilibrium diagramme diagrame in layers

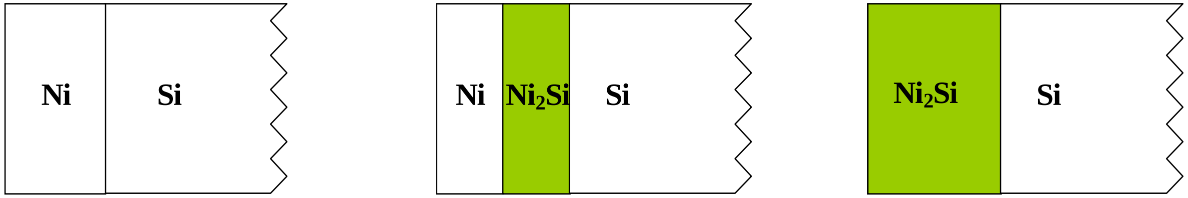
Diffusion couple : Ti/Si



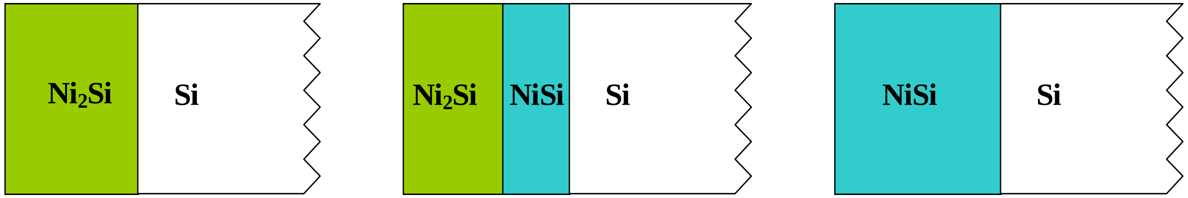


L # √t →diffusion controlled growth

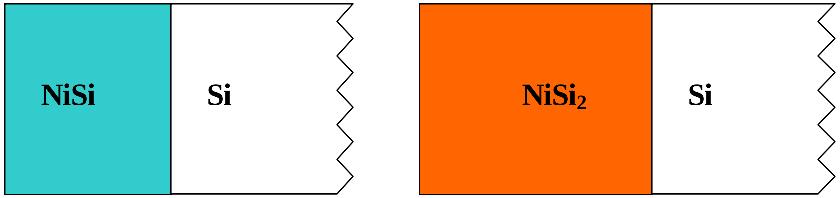
Reaction of Ni thin films with Si



T ~ 200-300°C : formation of Ni_2Si : DIFFUSION controlled , Ni diffusion



T ~ 250-350°C : formation of NiSi : DIFFUSION controlled , Ni diffusion



T ~ 750-800°C : formation of $NiSi_2$: NUCLEATION controlled , Ni diffusion

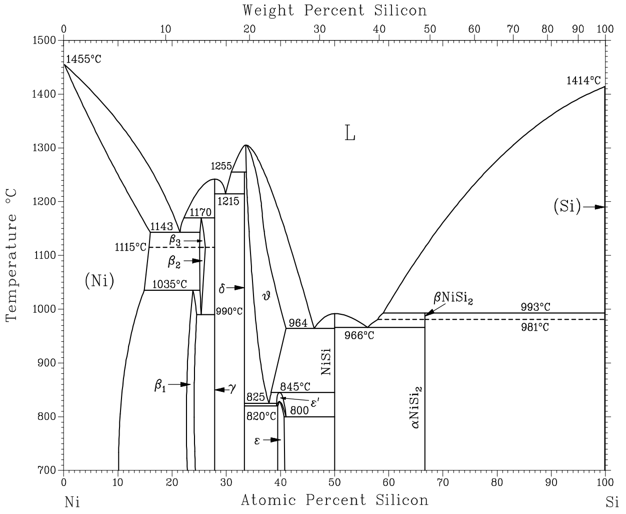
Nanometric thickness

[Lavoie et al Microelec. Eng. 2003]

- **new phases?**
- **“transient” phases**
- **kinetic ?**

Submicron thickness

- **sequential formation**
- **3 phases: Ni_2Si, NiSi, $NiSi_2$**
- **diffusion of Ni**



≠ Ni-Si phase diagram

→Better understanding of the growth mechanisms

Reactive diffusion in microelectronics: outline

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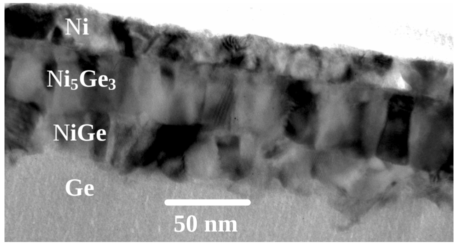

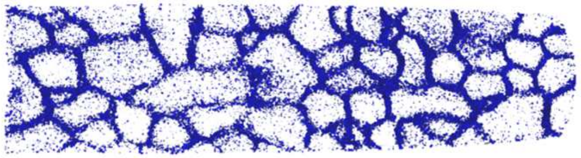

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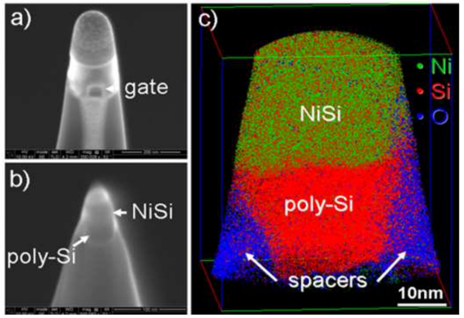

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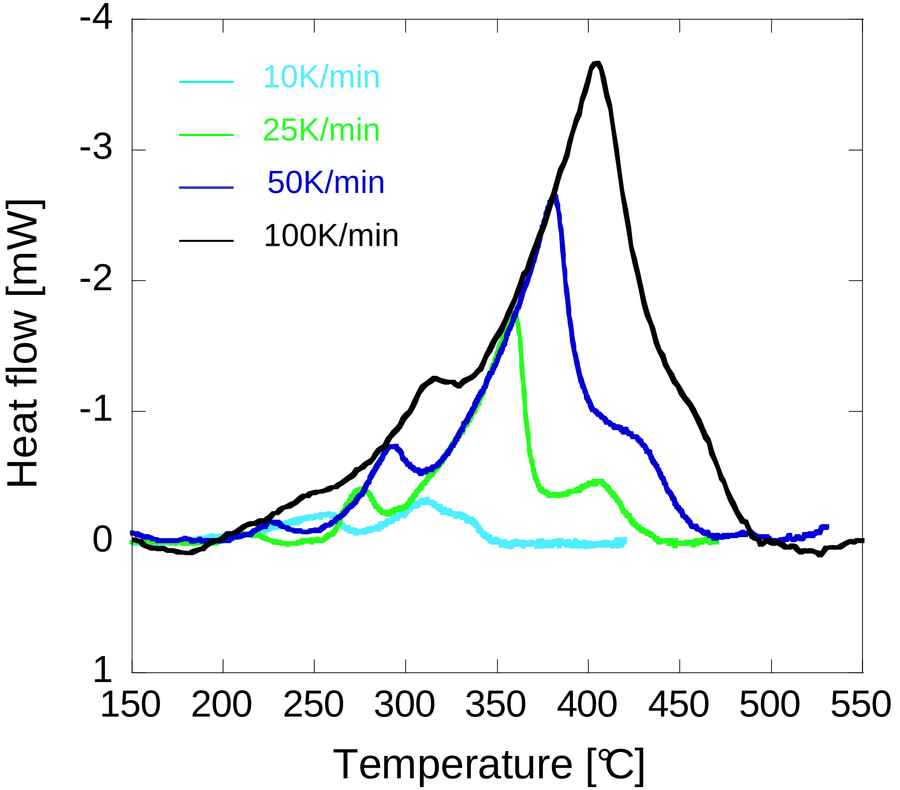
Reaction of Ni thin films with Si: DSC

Differential scanning calorimetry (DSC)

- Advantages of DSC
  - → Thermodynamics
  - → Sensitivity to first stages of formation
- Limits of DSC
  - → Quantity of materials
  - → Substrate “noise”

Nemouchi et al, APL, 2005



DSC thermograms of 50 nm Ni films on a-Si with different ramps

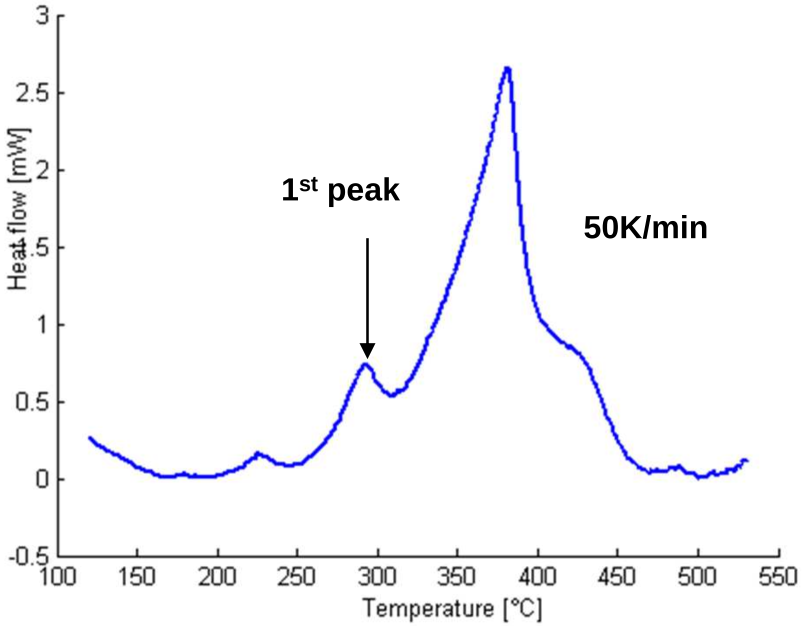
DSC analysis of reaction of 50 nm Ni films with a-Si on a Si substrate

Lateral growth of NiSi at the Ni_2Si/Si interface

2 DSC peaks for Ni_2Si

1st Peak → lateral growth (LG) of nuclei

2nd Peak → normal growth (NG)

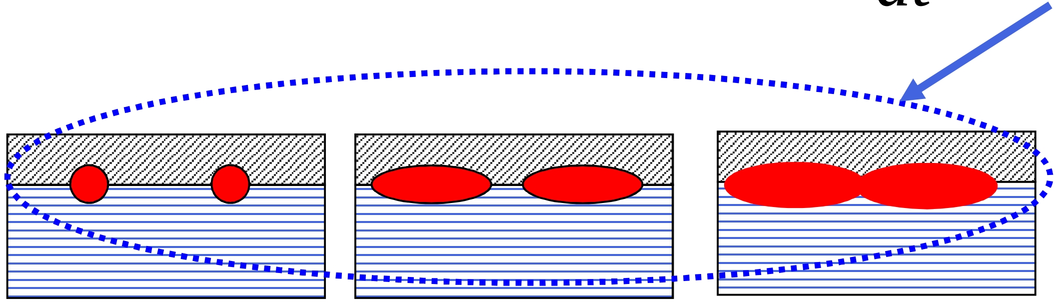


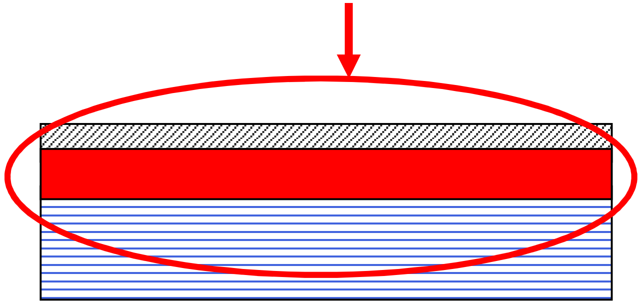
model : Coffey *et al APL 1989*

- Density of existing nuclei
- Cylindrical nuclei of radius r
- Lateral growth (LG) controlled by interface mobility

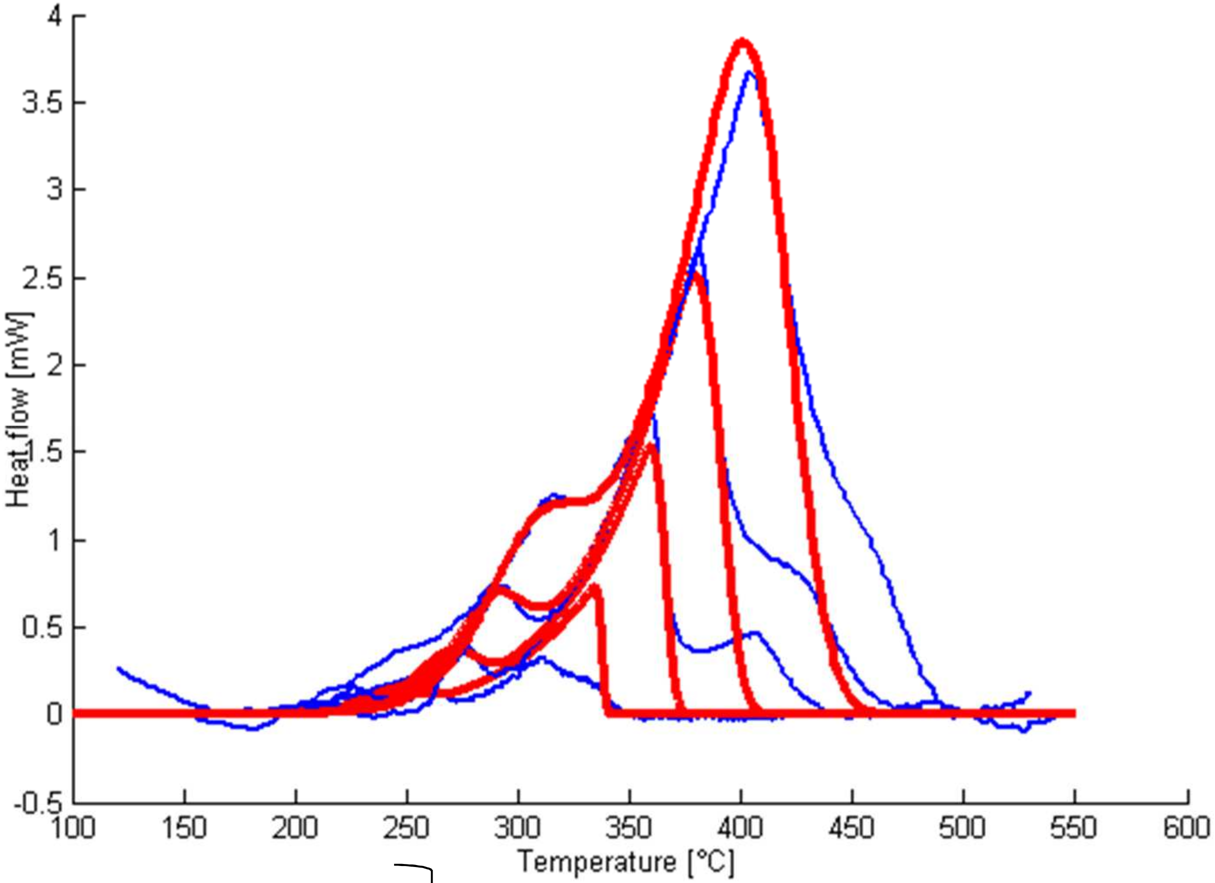
Transformed volume fraction:

$$\frac{dXv}{dt} = \frac{dX_A}{dt}\frac{L}{L_0} + X_A\frac{dL}{dt}\frac{1}{L_{\max}}$$





Lateral growth of NiSi at the Ni_2Si/Si interface



LG: $$\frac{dr}{dt} \propto K_{LG}$$

NG: $$\frac{dL}{dt} \propto \frac{D}{L + D/K_{NG}} \frac{\Delta G}{RT}$$

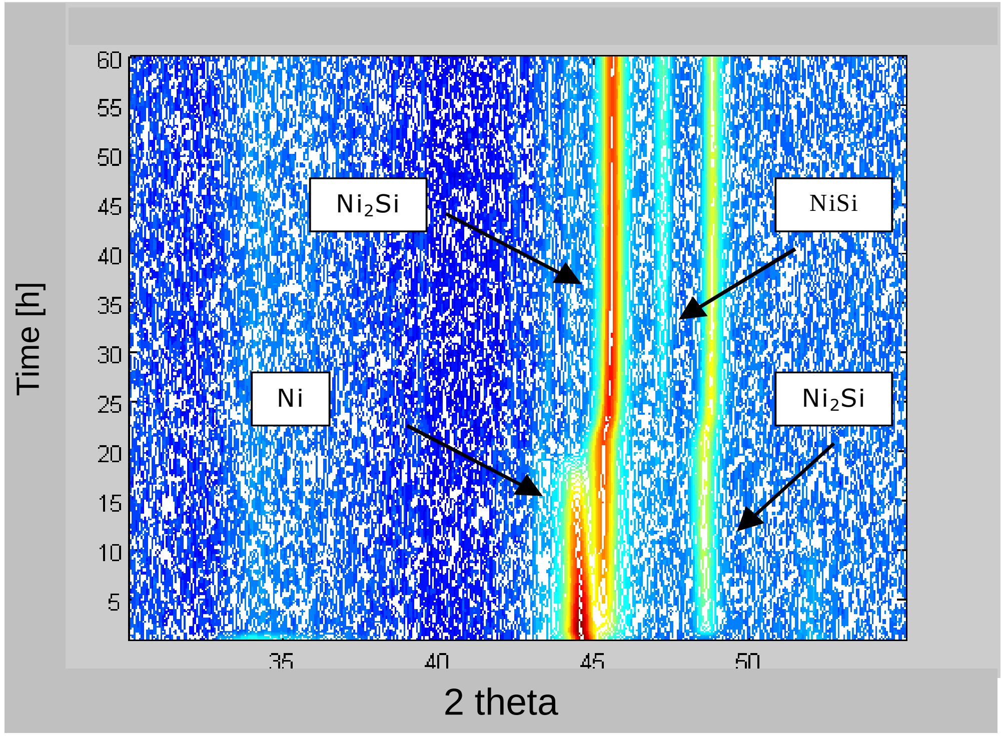
→Interface mobility for lateral growth:

→K_{LG}=10 exp(-0.85/kT) [cm/s]

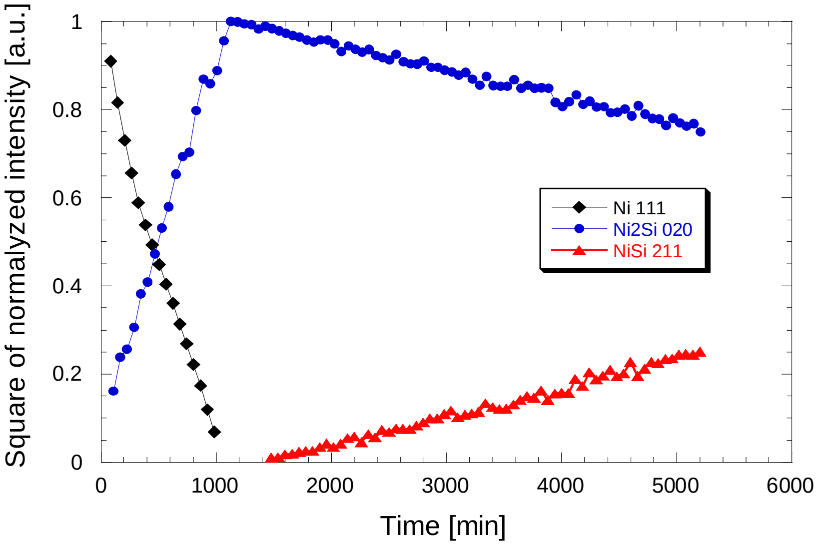
D. Mangelinck, ANF Métallurgie, 22-25 octobre 2012, Aussois

Reaction of Ni thin films with Si: XRD

Reaction between a 50 nm film of Ni and amorphous Si



In situ X ray diffraction for the annealing at 210°C of a 50 nm Ni film on amorphous Si



Normalized intensity of X ray diffraction peaks for the annealing at 210°C of a 50 nm Ni film on amorphous Si

$L \propto \sqrt{t}$ → **Diffusion controlled growth**

D. Mangelinck, ANF Métallurgie, 22-25 octobre 2012, Aussois

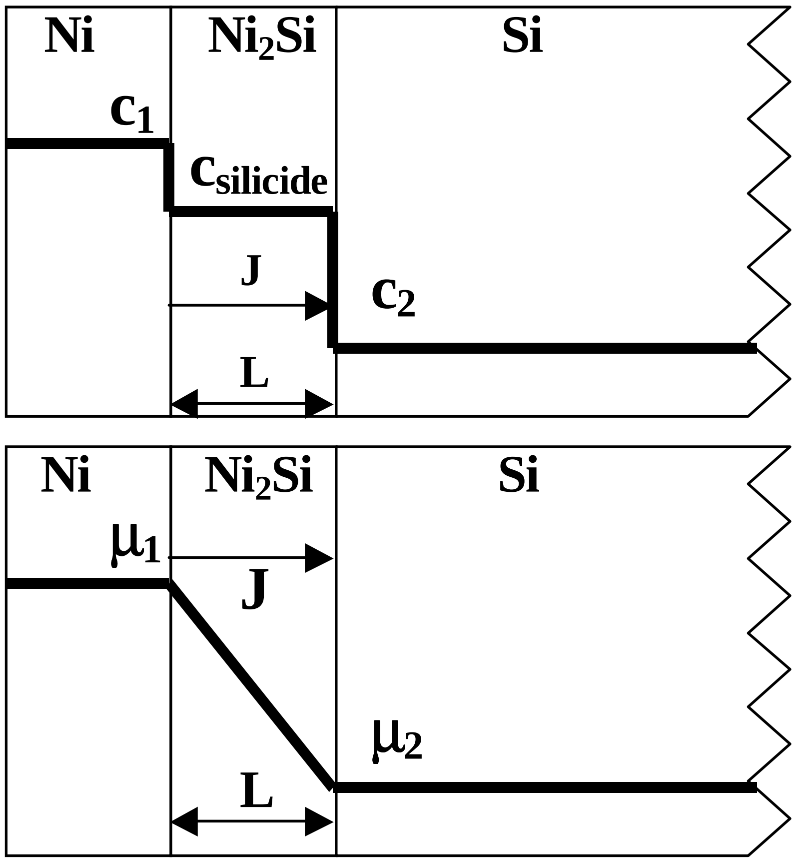
Nernst Einstein formalism

P Gas - FM d'Heurle: J. Mat. Res 1986, Landolt-Börnstein 1998 …

- Fick law: $J = -D\frac{dc}{dx}$
  - stœchiometric phase !
  - unknown or inappropriate limits of composition !!
- **Nernst Einstein**
  - J = v C ; v = migration velocity;

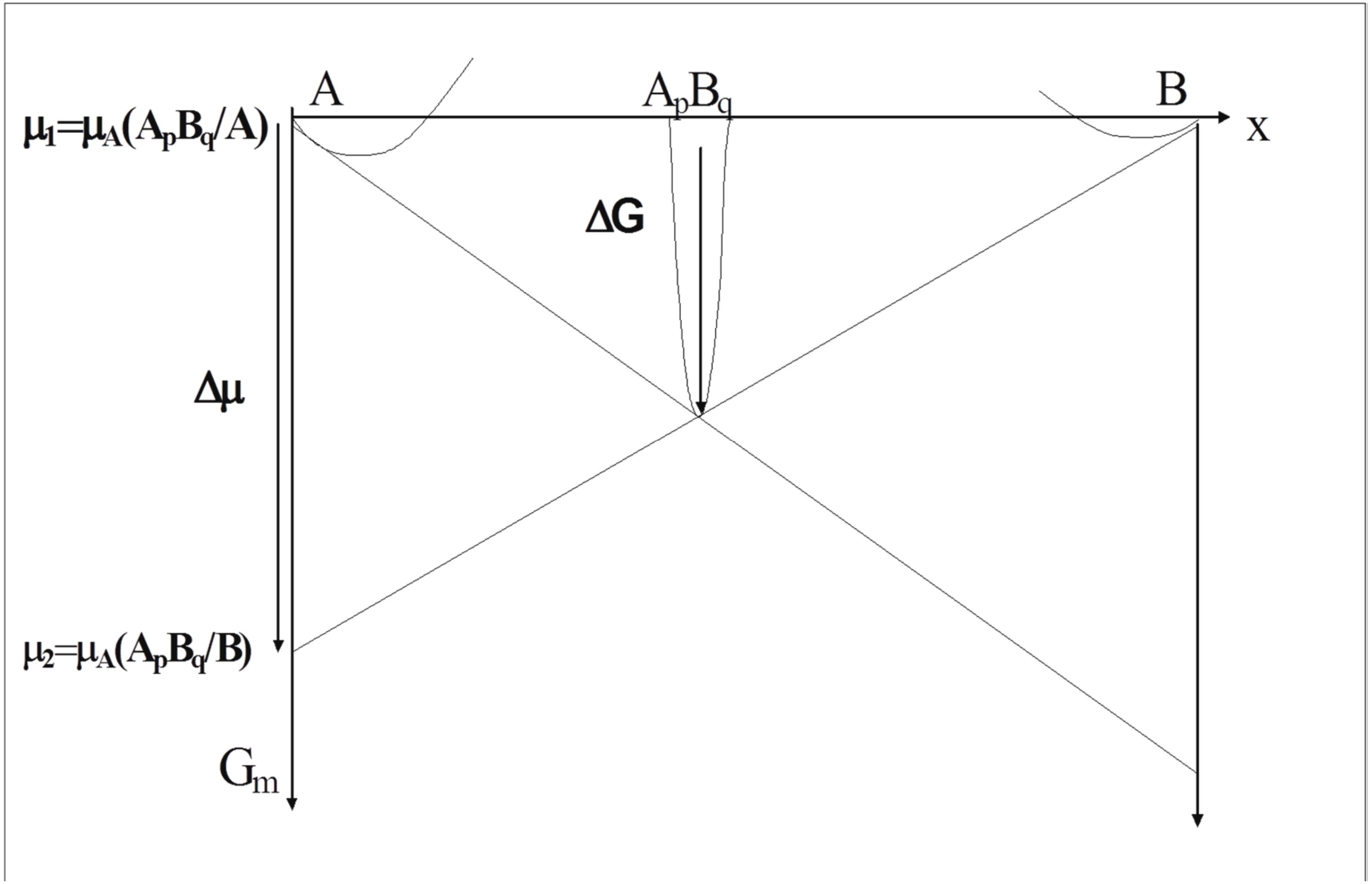
    v = -M (dμ/dx) ; M = mobility = D/RT
  - **Nernst Einstein relation :** $J = -C\frac{D}{RT}\frac{d\mu}{dx}$
- Formation of a phase
  - dμ/dx ~ **D**G/L

    ΔG: free energy of formation
  - $$\frac{dL}{dt} = \frac{\Delta G}{RT}\frac{D}{L} \rightarrow L^2 = 2D\frac{\Delta G}{RT}t$$



Parabolic growth

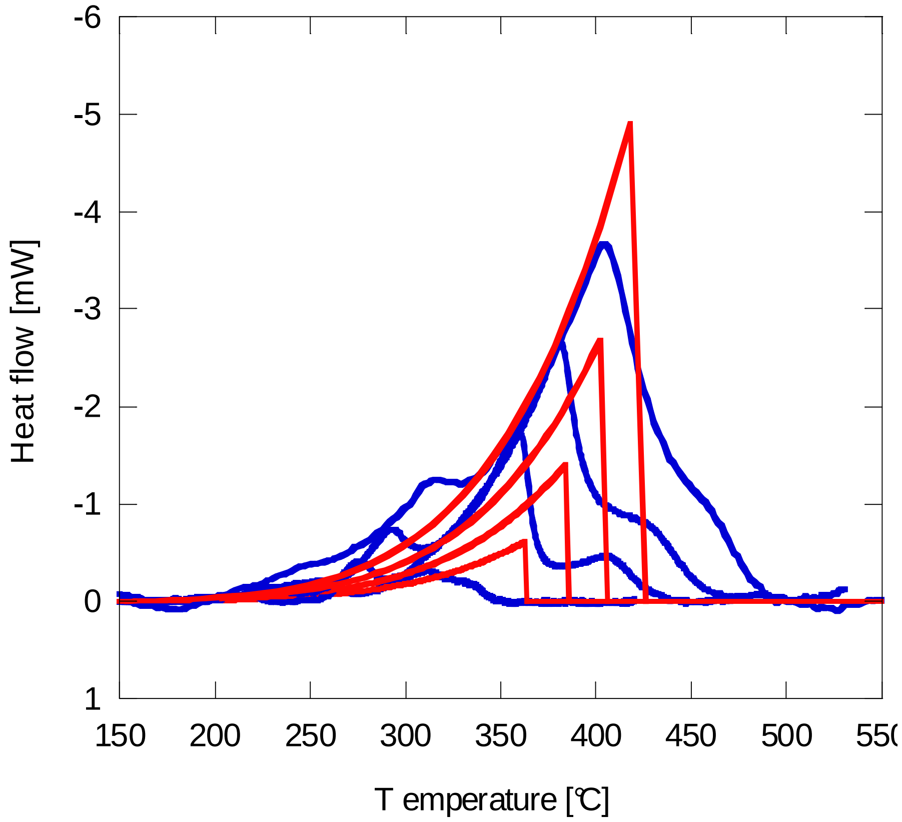
Variation of chemical potential across the growing phase



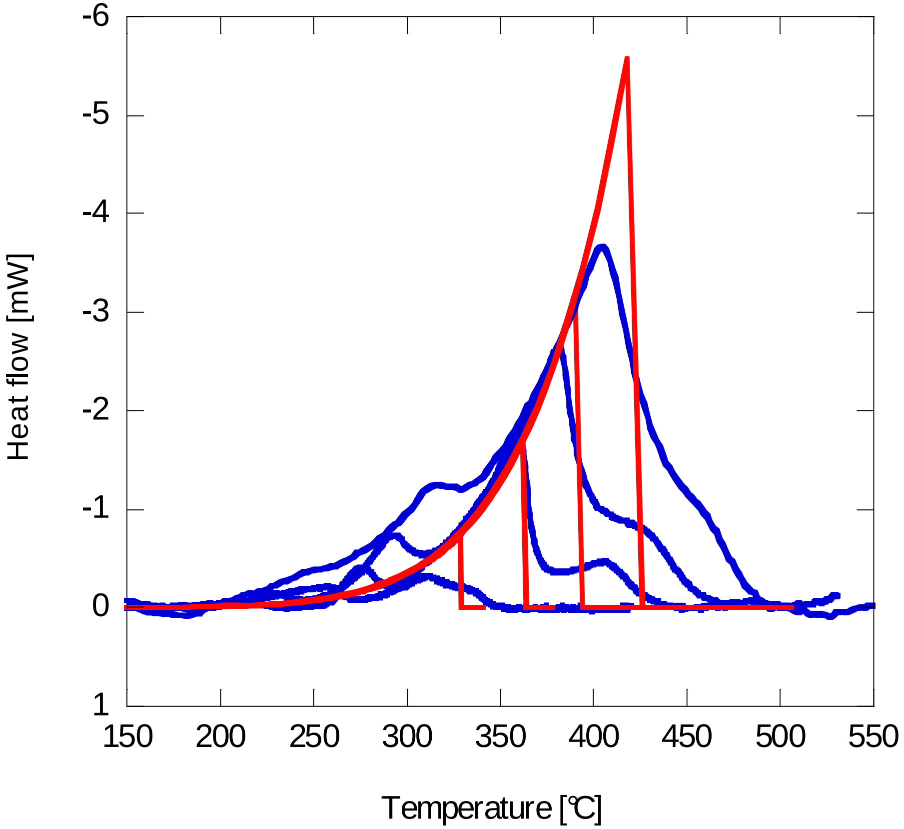
$$d\mu/dx \sim \Delta G/L$$

Interface/ diffusion controlled growth

Simulation of the normal growth



Diffusion controlled growth



Interface controlled growth

Grain growth and interface motion

- effective flux from grain 1 to grain 2

$$A_2n_1v_1\exp\left(-\Delta G^a/RT\right)$$

- effective flux from grain 2 to grain 1

$$A_1n_2v_2\exp\left(-\left(\Delta G^a+\Delta G\right)/RT\right)$$

- equilibrium $A_1n_2v_2=A_2n_1v_1$

- net flux

$$J_{net}=A_2n_1v_1\exp\left(-\frac{\Delta G^a}{RT}\right)\left(1-\exp\left(-\frac{\Delta G}{RT}\right)\right)$$

$$J_{net}=A_2n_1v_1\exp\left(-\frac{\Delta G^a}{RT}\right)\left(\frac{\Delta G}{RT}\right)$$

$$\boxed{v=\Omega J_{net}=K\Delta G}$$

Si ΔG = 0, v = 0 → no growth

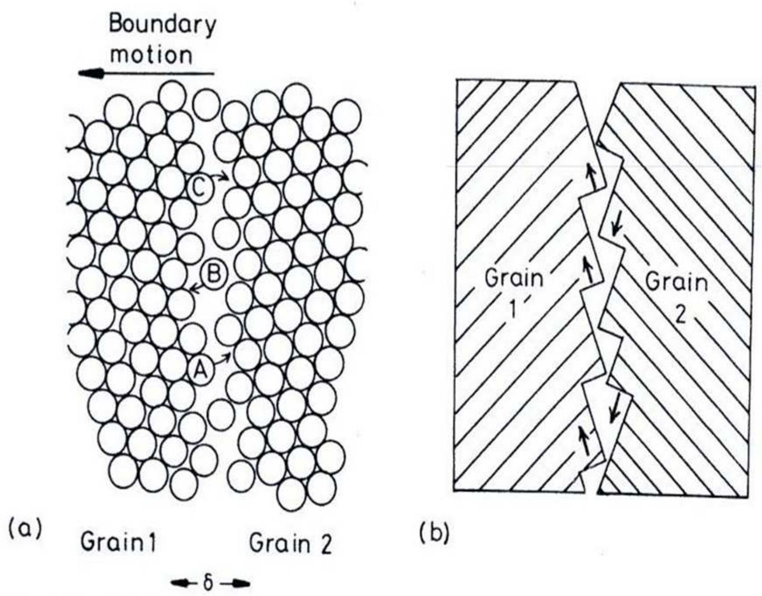


Fig. 3.23 (a) The atomic mechanism of boundary migration. The boundary migrates to the left if the jump rate from grain 1 → 2 is greater than 2 → 1. Note that the free volume within the boundary has been exaggerated for clarity. (b) Step-like structure where close-packed planes protrude into the boundary.

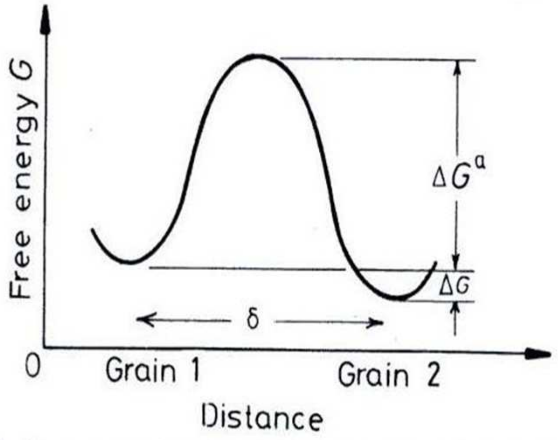


Fig. 3.24 The free energy of an atom during the process of jumping from one grain to the other.

Interface/ diffusion controlled growth

- Growth of Ni_2Si: $\frac{dL}{dt} = -\frac{1}{\Omega} J$

- Diffusion in Ni_2Si (Nernst-Einstein)

$$J = -\frac{1}{\Omega}\frac{D}{RT}\overrightarrow{\nabla\mu} = -\frac{1}{\Omega RT} D \frac{\mu_2 - \mu_1}{L}$$

$$\frac{dL}{dt} \propto \frac{D}{L} \qquad Isotherm \Rightarrow L \propto \sqrt{t}$$

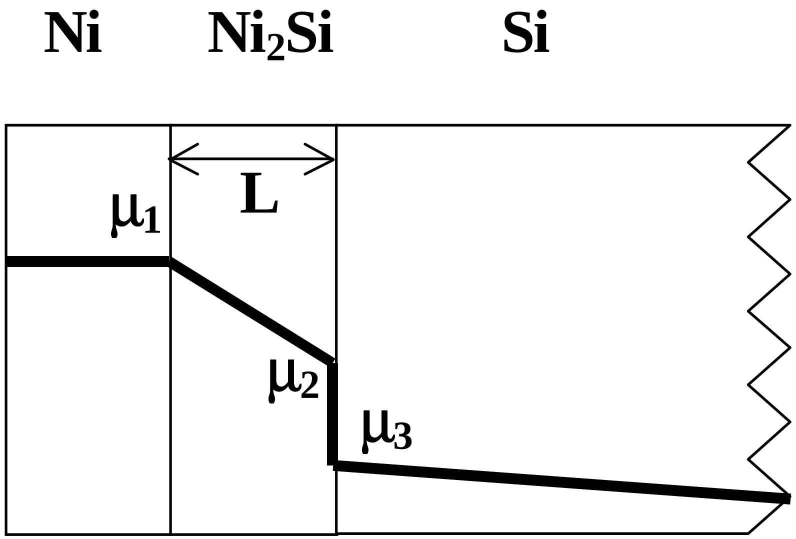
- Reaction at the interface

$$J = \frac{1}{\Omega}\frac{K}{RT}\Delta\mu = \frac{1}{\Omega RT} K(\mu_3 - \mu_2)$$

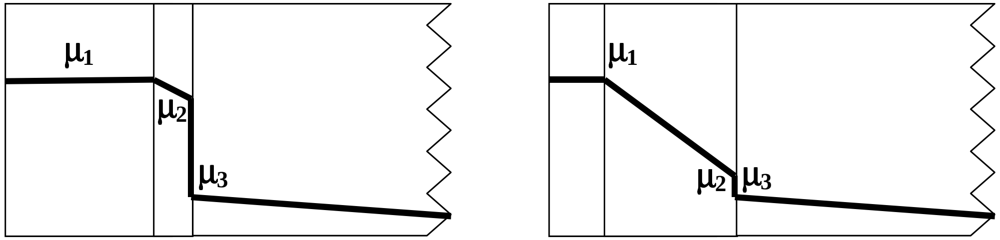
$$\frac{dL}{dt} \propto K \qquad Isotherm \Rightarrow L \propto t$$

- Deal & Groove law :

$$\frac{dL}{dt} = \frac{D}{L + D/K}\frac{\mu_3 - \mu_1}{RT}$$



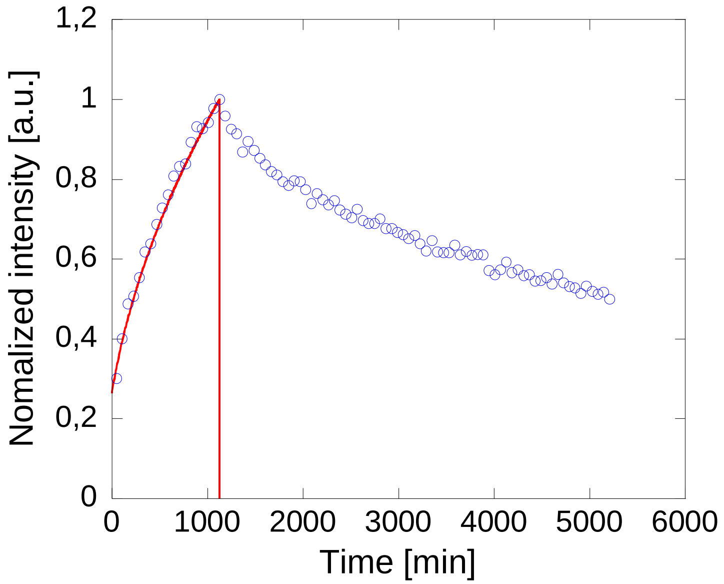
Linear-parabolic growth



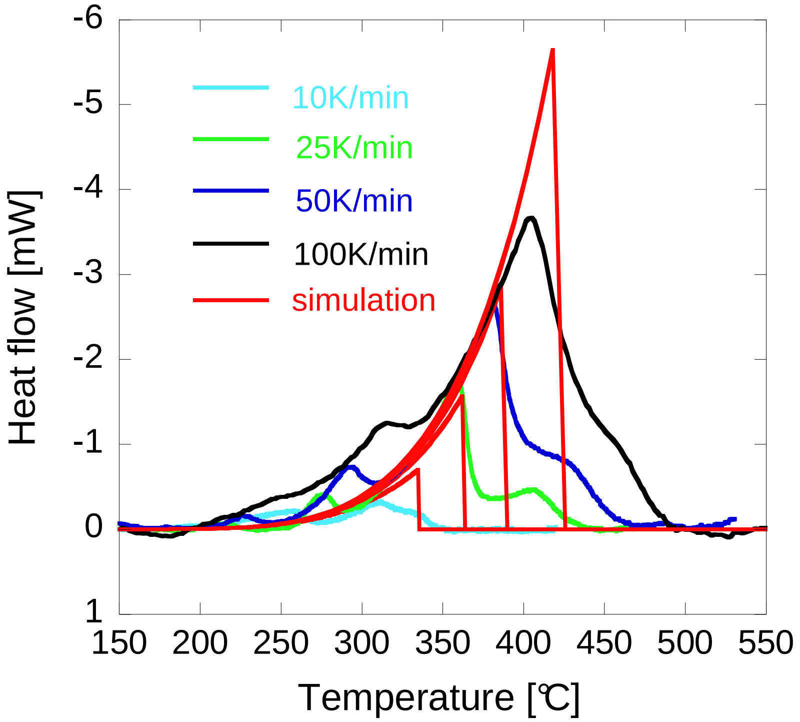
L petit **L grand**

Isotherm ➔linear parabolic growth

Interface/ diffusion controlled growth



Simulation of XRD results (210°C)



Simulation of DSC results

Linear parabolic growth :

→Interface : K_n = 0.25 exp(-0.8/kT) [cm/s]

→Diffusion : D = 1.67 exp(-1.5/kT) [cm^2/s]

K_n = interface mobility (attachment, reaction, vacancy annihilation…)

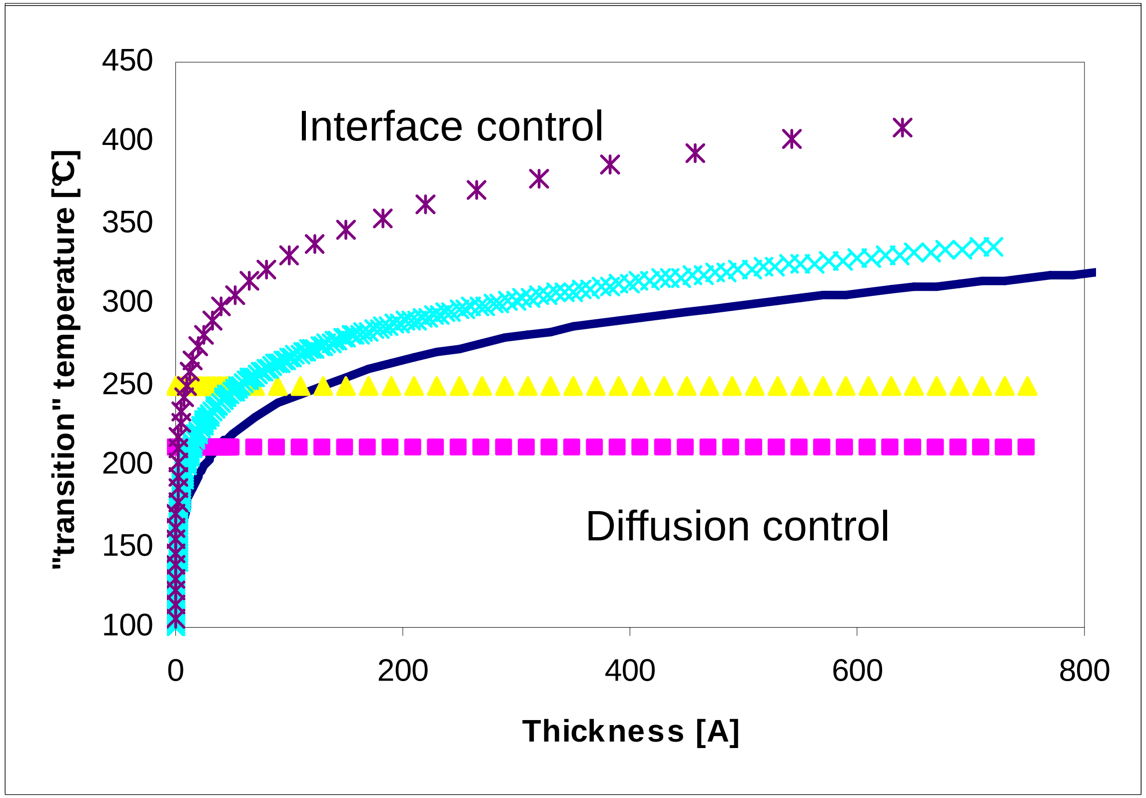
Interface/ diffusion controlled growth

- Deal and Groove law:

$$\frac{dL}{dt}=\frac{D}{L+D/K}\frac{\mu_3-\mu_1}{RT}$$

- transition thickness or transition temperature :

$$L_t=\frac{D}{K}\Rightarrow \quad T_t=\frac{E_D-E_i}{k_B\ln\left(\frac{D_0}{L_t v_0}\right)}$$

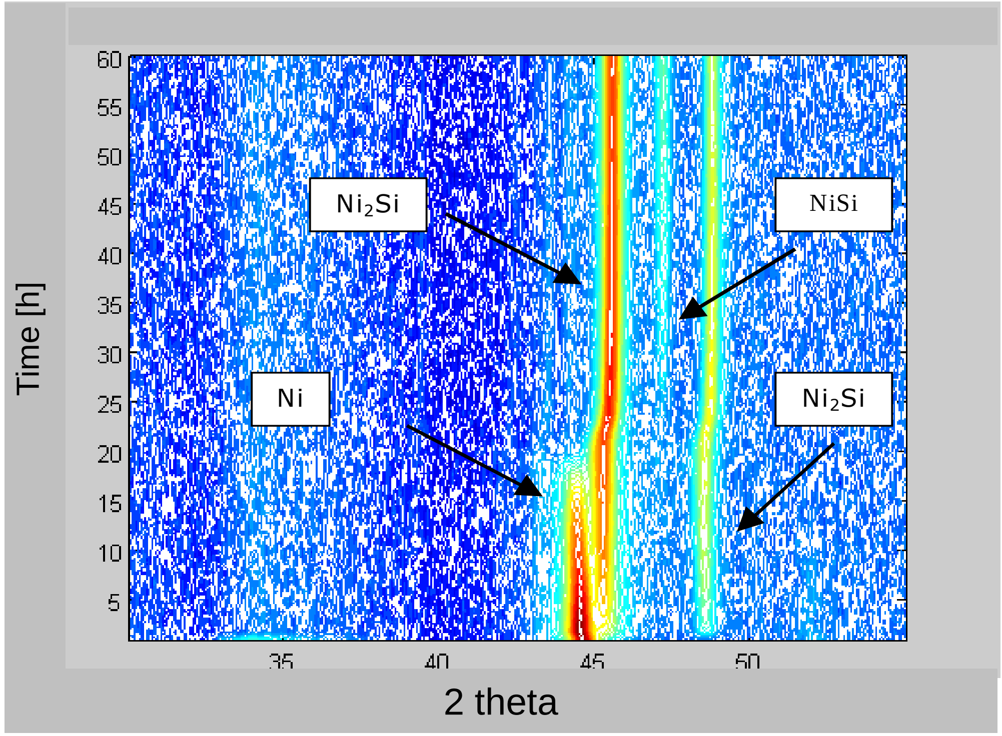


- T >> T_t or L << L_t → interface controlled growth → isotherm: linear growth
- T << T_t or L >> L_t → diffusion controlled growth → isotherm: parabolic growth

High temperature (RTP), small thickness → interface controlled growth
Sequential growth linked to interface control

Reaction of Ni thin films with Si: XRD

Reaction between a 50 nm film of Ni and amorphous Si



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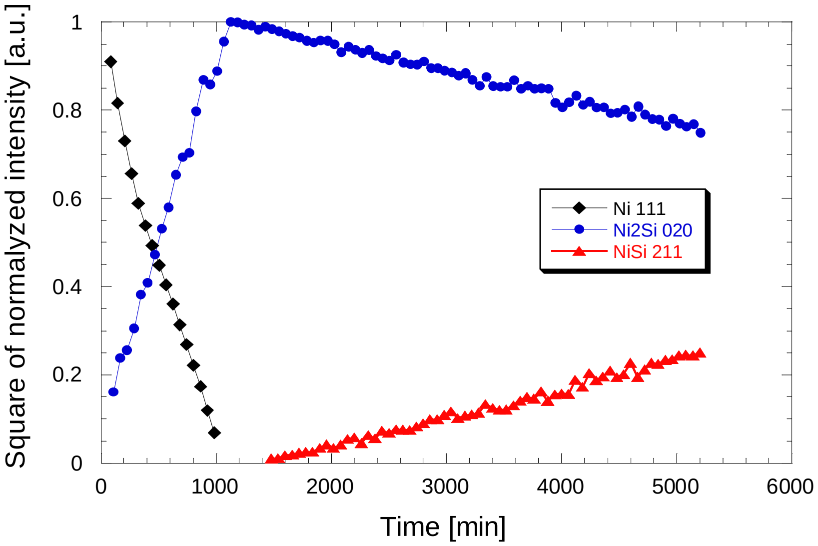
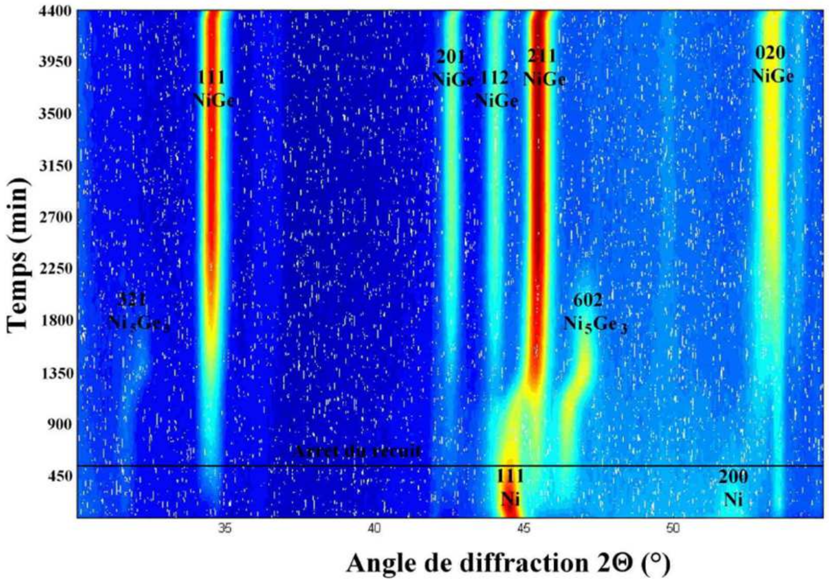


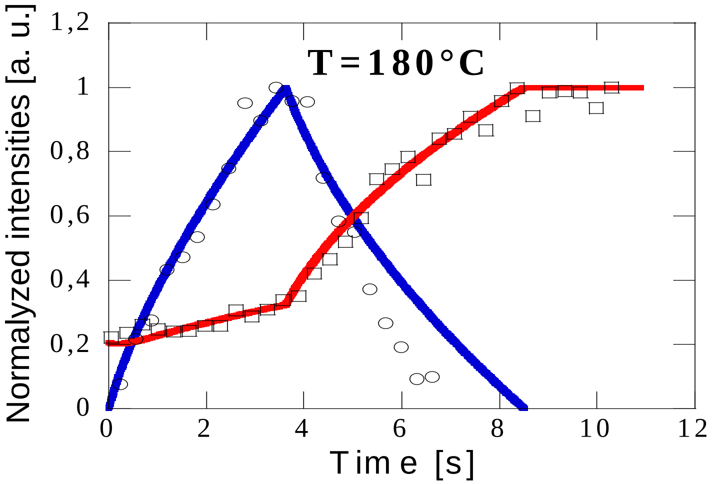
Normalized intensity of X ray diffraction peaks for the annealing at 210°C of a 50 nm Ni film on amorphous Si

→ **Sequential formation**

Reaction of Ni thin films with Ge

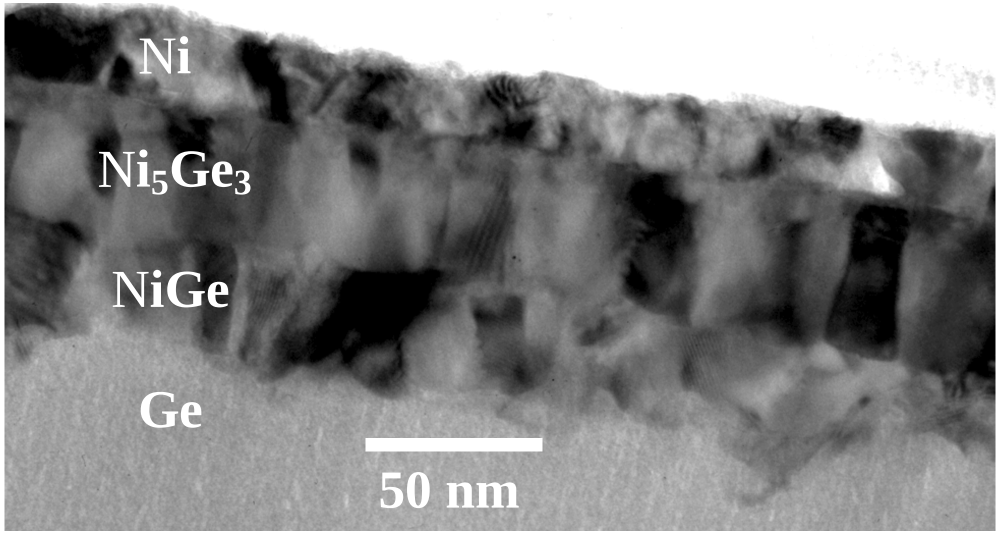


In situ XRD (T= 180°C) of a 50 nm Ni film on amorphous Ge



XRD intensities and simulation with linear-parabolic law

Nemouchi et al, APL, 2005

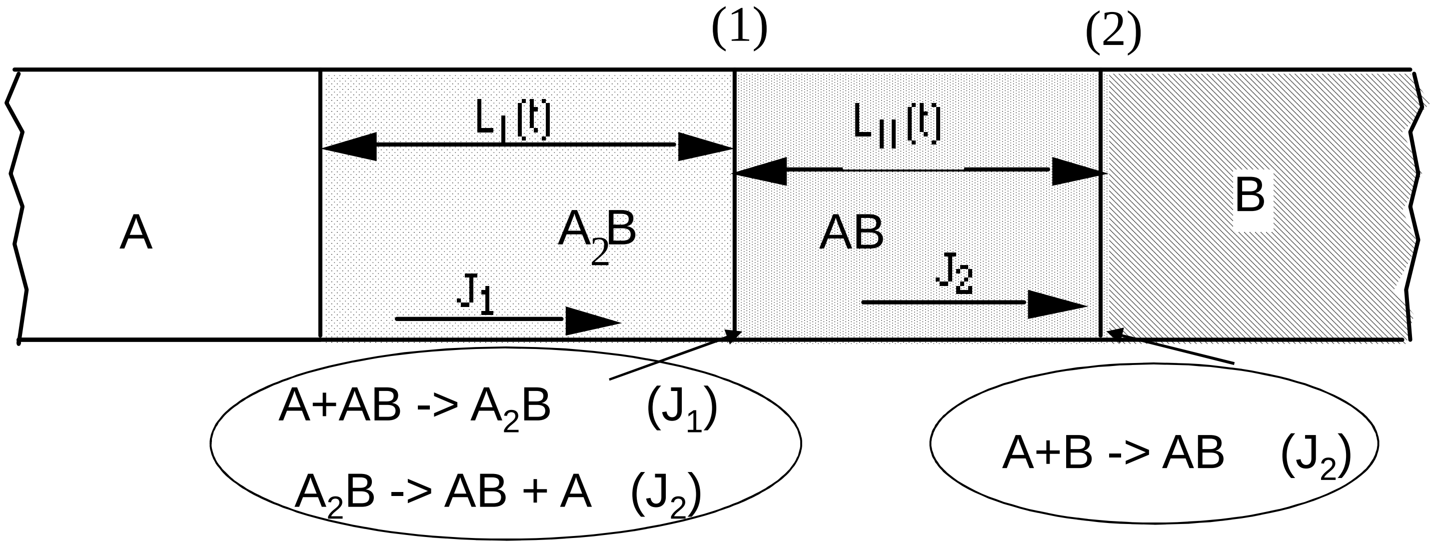


TEM images of a Ni/aGe sample annealed 100 min at 175°C

→ Simultaneous growth of Ni_5Ge_3 and NiGe

Phases selection : sequential formation

U. Gösele and K. N. Tu, JAP (1982) - P Gas and FM d'Heurle, Appl. Surf. Sci. 1993



$$\frac{dL_1}{dt} \propto J_1 - J_2$$

$$\frac{dL_2}{dt} \propto -J_1 + 2J_2$$

At the begining of phase 2 growth for
Phase 1: diffusion control
Phase 2 : interface control

$$\frac{dL_2}{dt} \propto 2K_2 - \frac{D_1}{L_1}$$

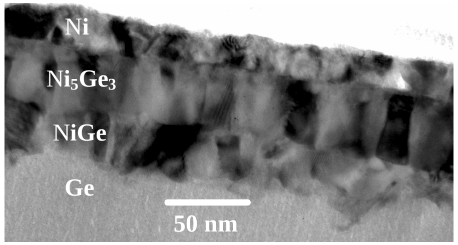
$$\frac{dL_2}{dt} > 0 \Rightarrow L_1 > \frac{D_1}{K_2}$$

Phase 1 has to reach a critical thickness before phase 2 can grow

→ **Simultaneous formation or sequential formation**

$$L_c\ (Ni/Ge) < L_{Ni} < L_c\ (Ni/Si)$$

Reactive diffusion in microelectronics: outline



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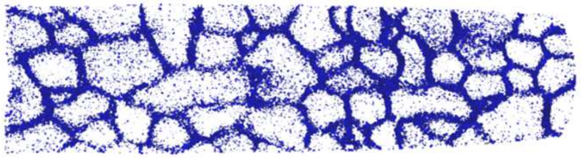

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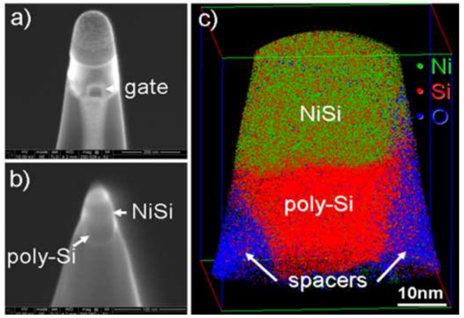

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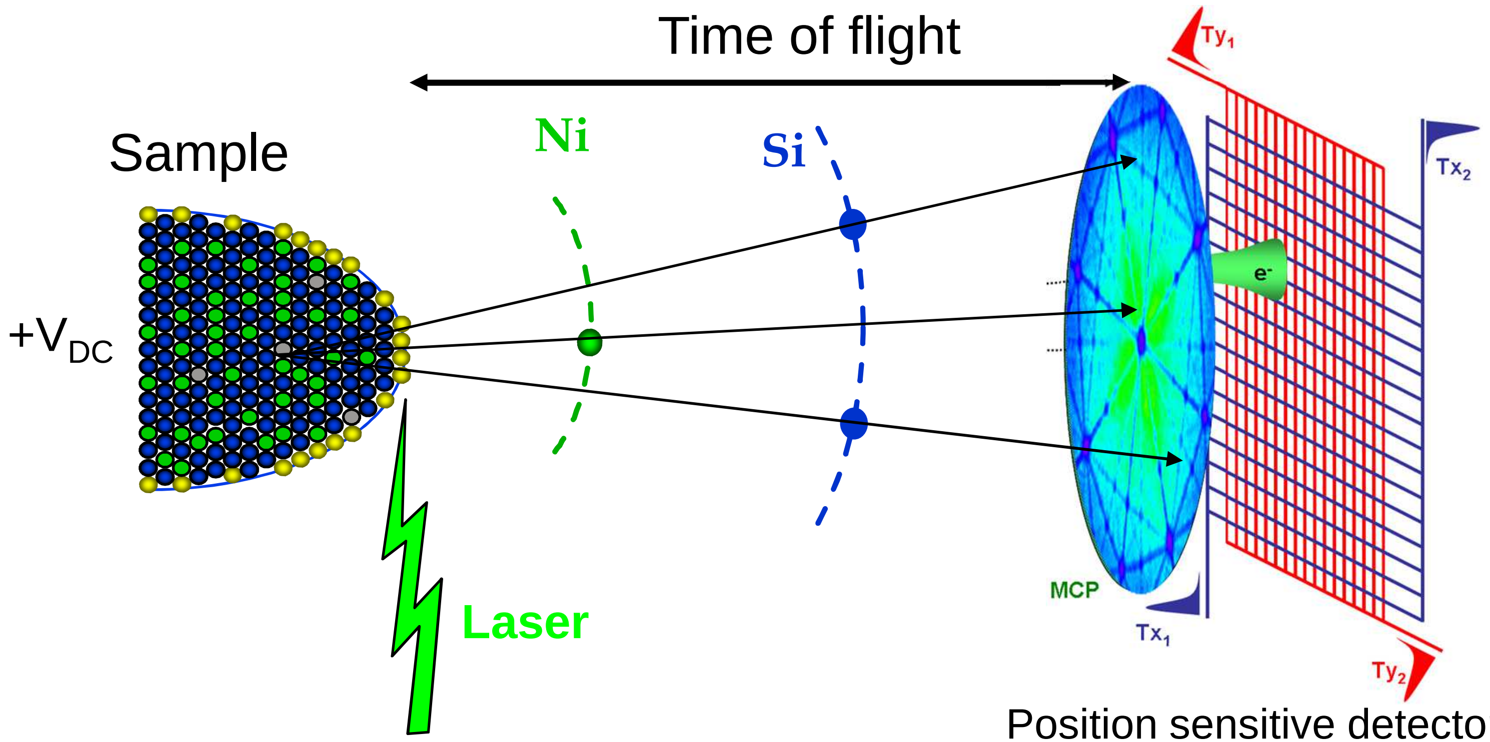
Atom Probe Tomography

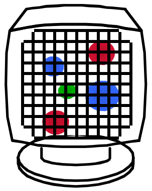
Ions field emission: high voltage (V_{DC})+ pulsed laser



Position sensitive detector = MCP+DL

Time of flight ➡ Ion mass

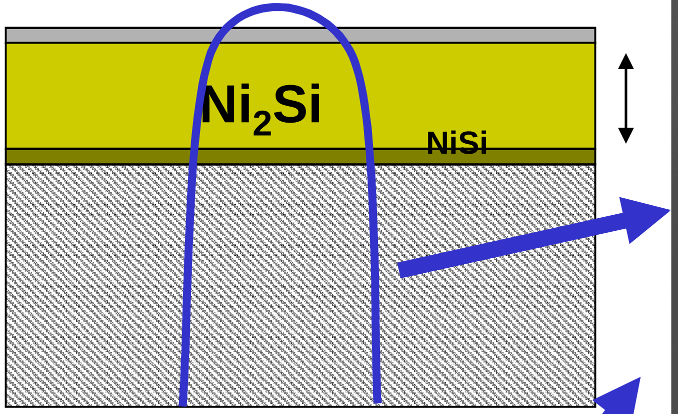
Impact position ➡ Original position



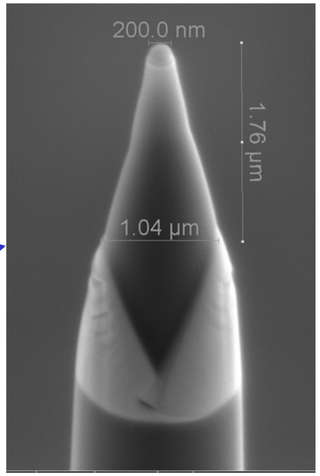
➡ 3D chemical map

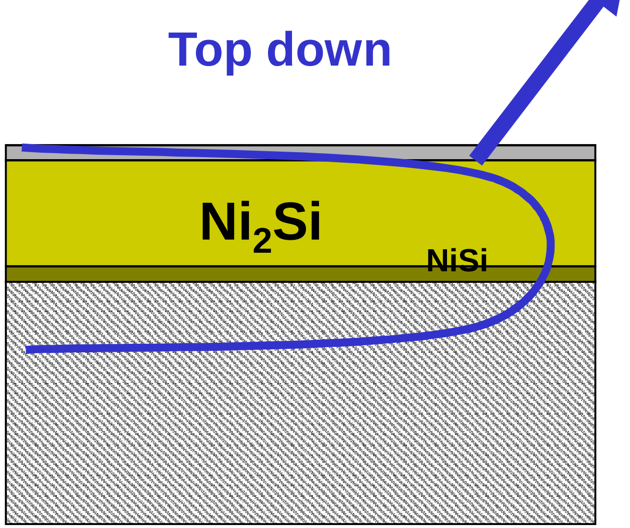
Atom probe tomography: sample preparation

Tip preparation by FIB



Top down

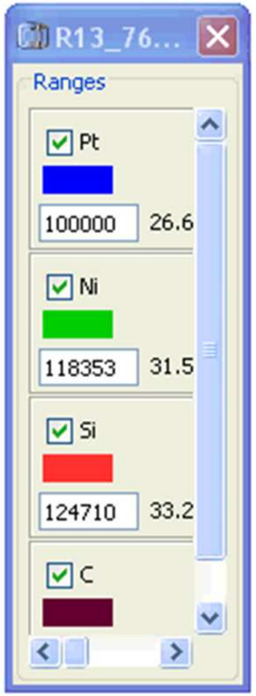




Cross section

LEAP3000XHR:
- **Mass resolution** :
  - M/DM(FWHM) > 1000
  - M/DM(FWTM) > 500
- **Typical diameter** : 100-200 nm
- Laser: Focalization and continuous control
- Local electrode
  - → simpler tip preparation by FIB
  - → less rupture

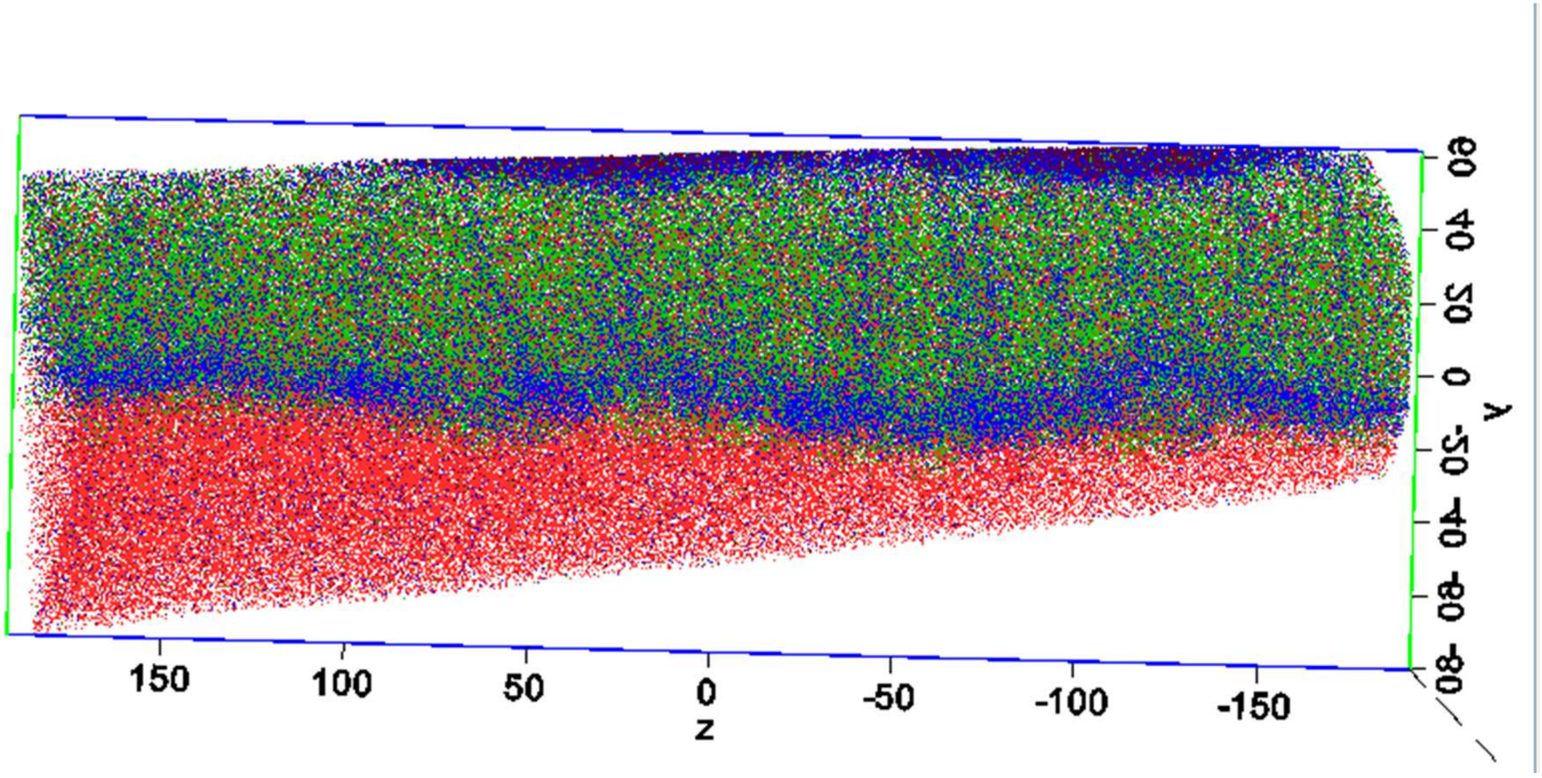
Reaction of Ni(Pt) with (100)Si



R13_76...

Ranges

☑ Pt	🟦	
100000	26.6	
☑ Ni	🟩	
118353	31.5	
☑ Si	🟥	
124710	33.2	
☑ C	■	



Thin film reaction: redistribution of Pt and Ni silicide formation

- LEAP3000XHR
  - T=50K,
  - Pulse: 200 kHz,
  - Laser energy= 0.6 nJ/pulse
  - Evaporation rate = 0.01 ions per pulse
  - **V = 120x120x400 nm^3**
  - **170 Millions of atoms**

- Each point = 1 atom
  - Red = Si
  - Green = Ni
  - Blue = Pt

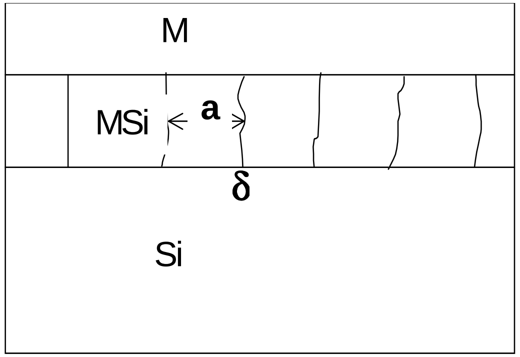
thin films / diffusion couples : grain boundaries?

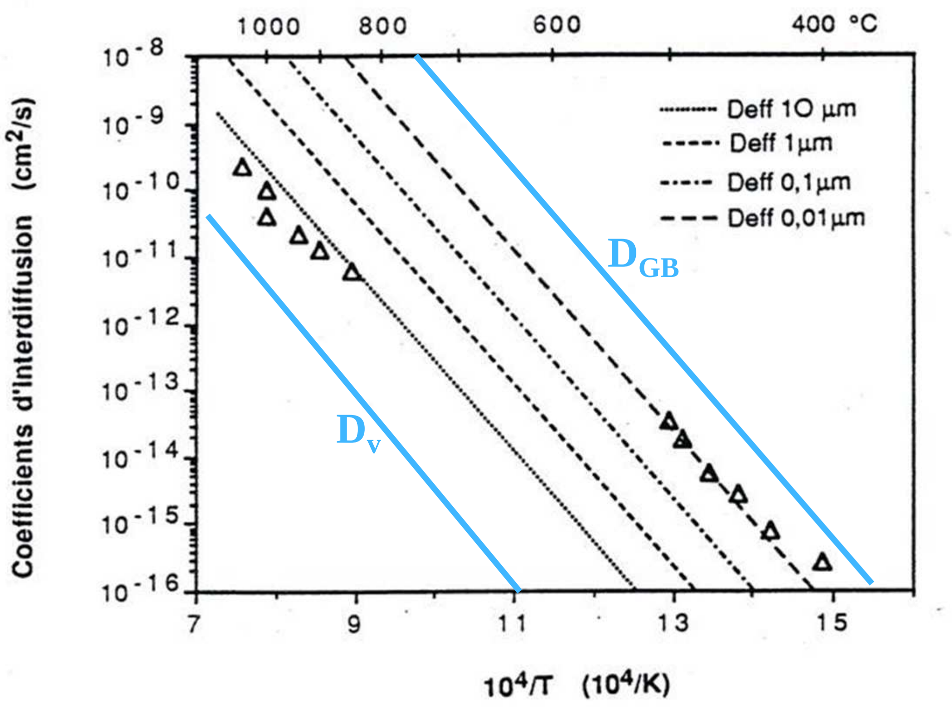
Barge et al, J Mat Res, 1995

- **Formation of $CoSi_2$**
  Difference: thin films – diffusion couple
  = Different mechanisms ?

- **Mesurement of selfdiffusion by radiotracers (^{60}Co, ^{68}Ge ~ Si)**

- $D_{eff} = D_v + (D_{gb} \times 2d/a)$
  d ≈ 5 10^{-8} cm; **a = 10-0,01 mm**





Comparison between interdiffusion coefficients obtained from growth rate of des taux de croissance de $CoSi_2$ in thin films and bulk diffusion couple

→ Role of grains boundaries diffusion

Diffusion of As in Ni_2Si

Fabrication process

1. Deposition of Ni and Si bilayers on a SiO_2 layer

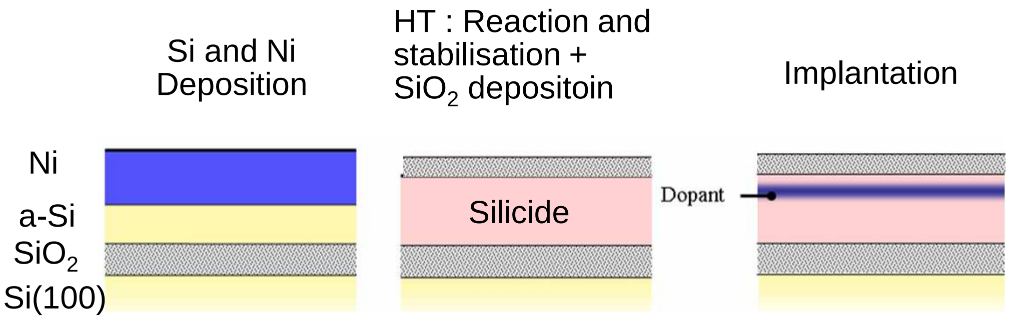
2. RTA to form the silicide

   → Si and Ni thicknesses are adjusted to form Ni_2Si or NiSi : controlled by XRD

3. SiO_2 deposition

4. Stabilization anneal : 700°C – 2h

   → Stabilize the grain size

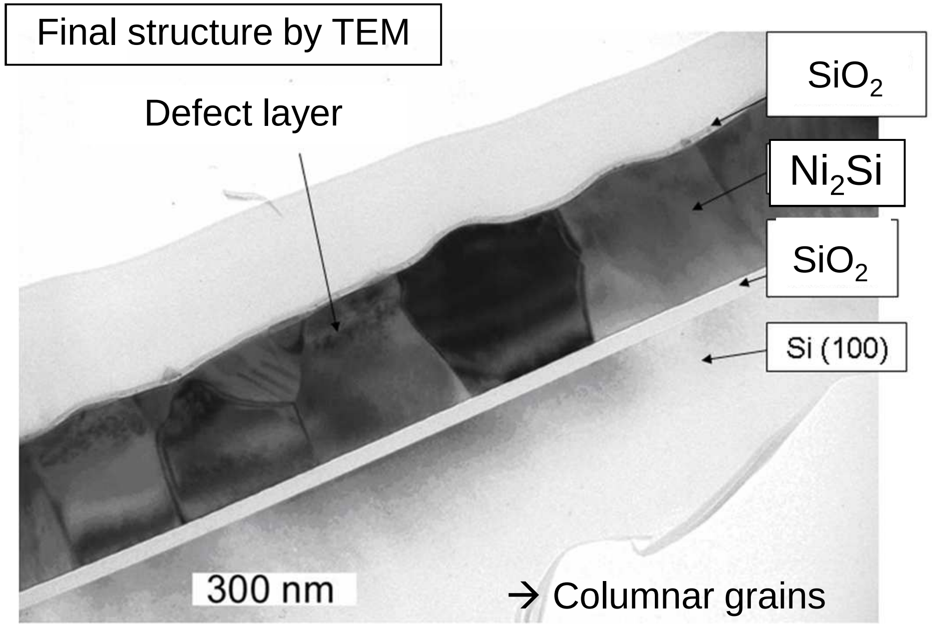


Oxide layers act as diffusion barriers :

- No reaction between the silicide and the substrate

- No outdiffusion or evaporation of the diffusing element

- Top oxide layer : less implantation damages

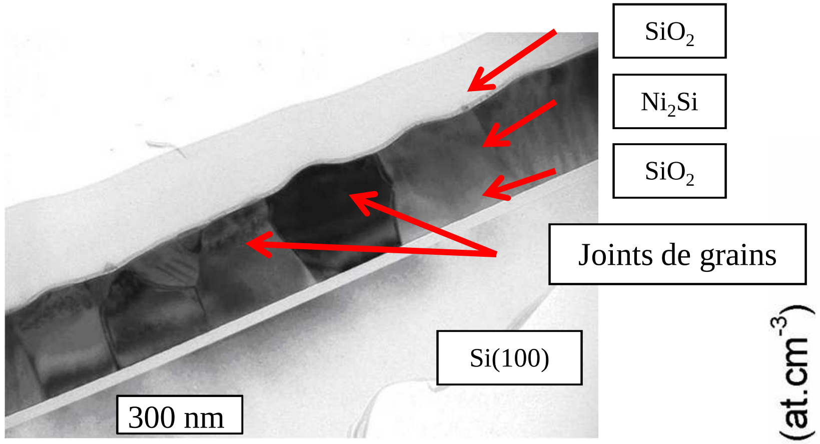

Final structure by TEM

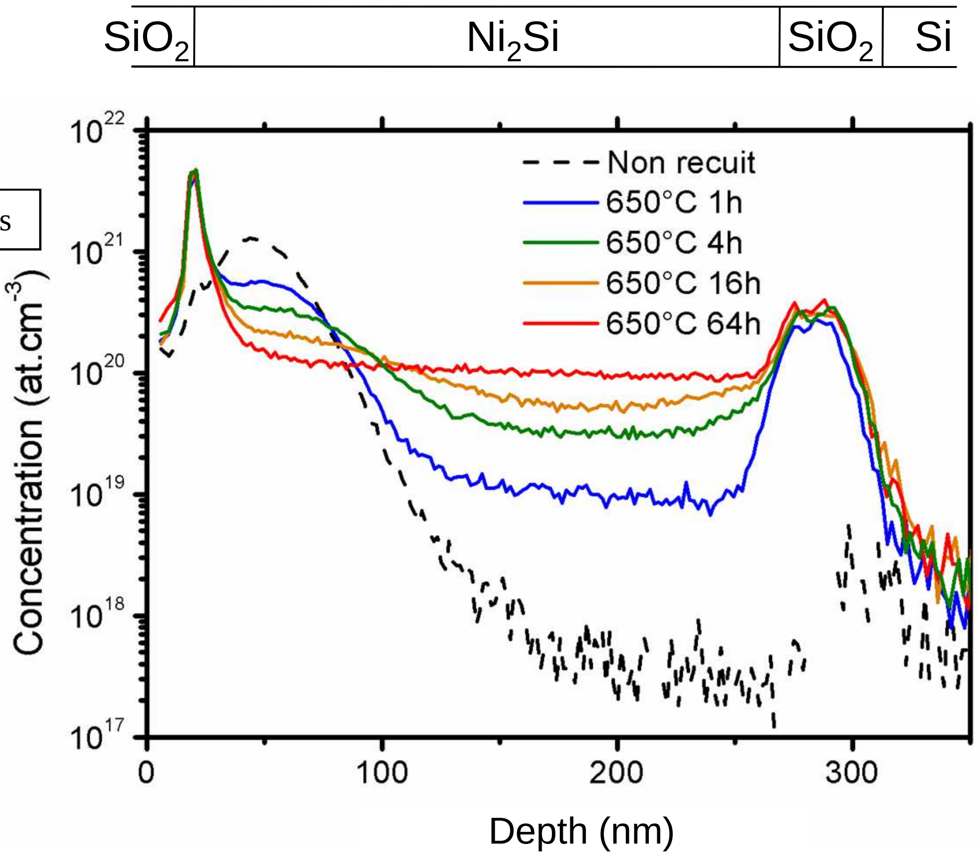
→ Columnar grains

5. Dopant implantation and diffusion annealing

As diffusion in Ni_2Si: T = 650°C

Heat treatments at 650°C + Depth profiles by SIMS



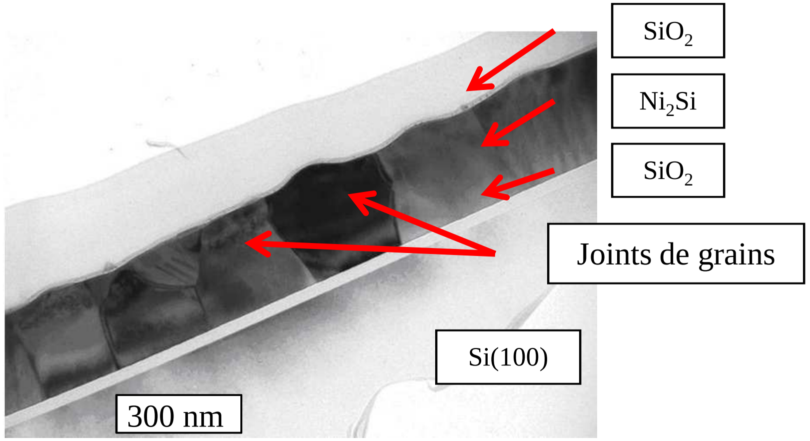


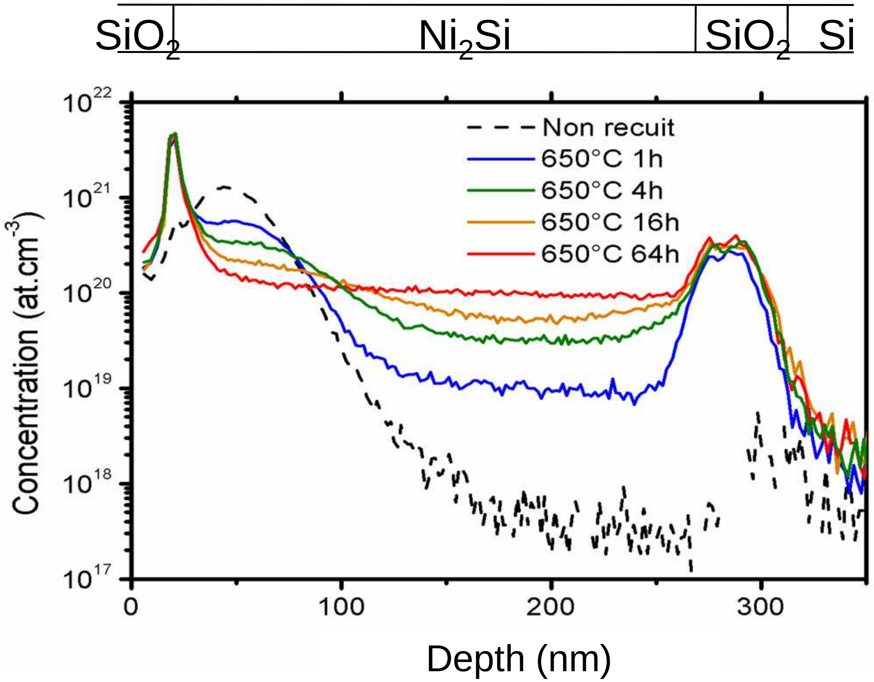
- Interface concentration has reached equilibrium after 1h.
- Flattening and broadening of the implantation peak : **Lattice diffusion**
- Diffusion tail : **GB diffusion**
- Concentration increase near the bottom interface : diffusion from the interface

Significant lattice diffusion at 650°C.

Profile shape explained by diffusion along the GBs and interfaces + slow lattice diffusion

As diffusion in Ni_2Si: T = 650°C

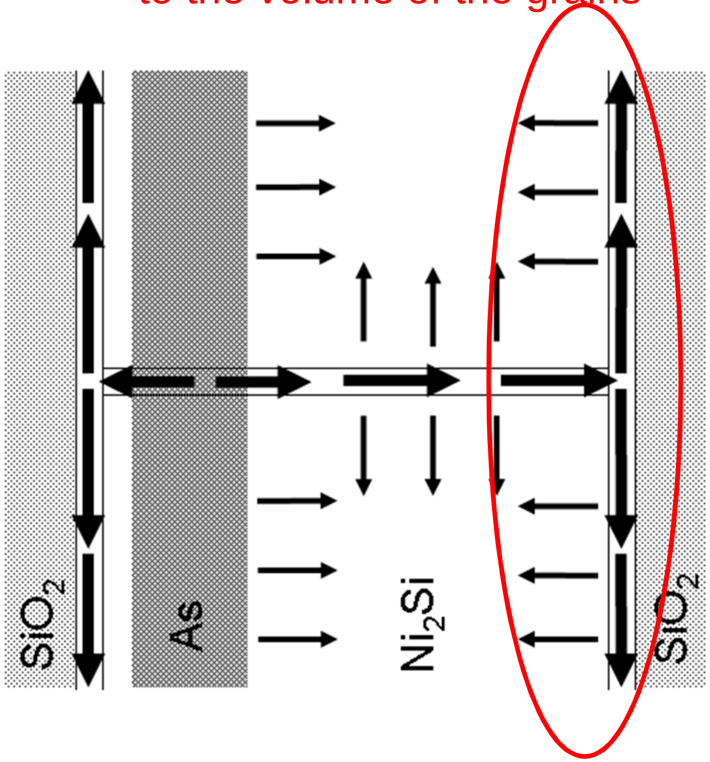




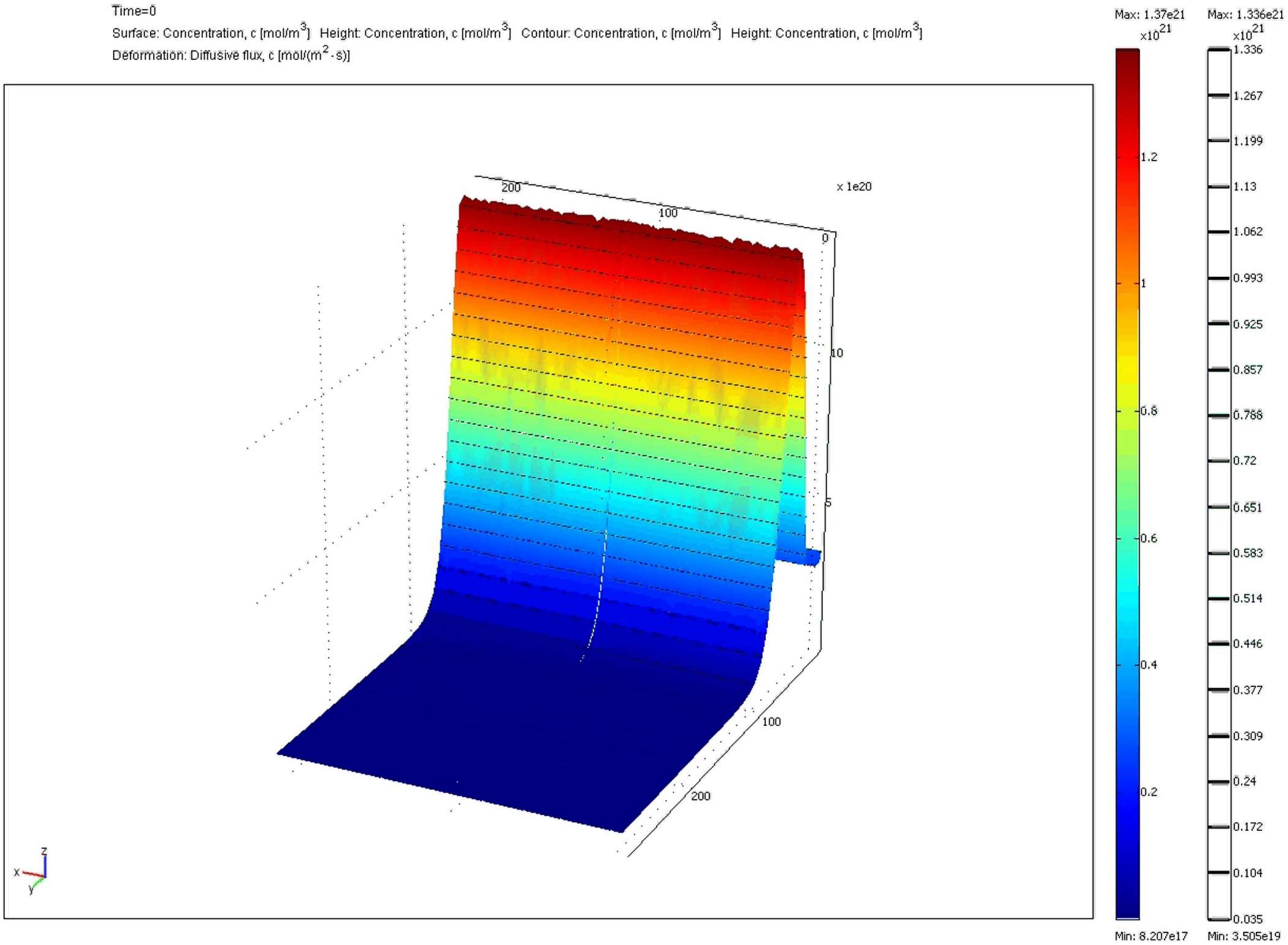
- Flattening and broadening of the implantation peak : **Lattice diffusion**

- Diffusion tail : **GB diffusion**

Diffusion from the bottom interface to the volume of the grains



Profile shape explained by diffusion along the GBs and interfaces + slow lattice diffusion


Time=0
Surface: Concentration, c [mol/m^3] Height: Concentration, c [mol/m^3] Contour: Concentration, c [mol/m^3] Height: Concentration, c [mol/m^3]
Deformation: Diffusive flux, c [mol/(m^2·s)]
x 1e20
200
100
0
10
5
100
200
z
x
y
Max: 1.37e21
x10^21
1.2
1
0.8
0.6
0.4
0.2
Min: 8.207e17
Max: 1.336e21
x10^21
1.336
1.267
1.199
1.13
1.062
0.993
0.925
0.857
0.788
0.72
0.651
0.583
0.514
0.446
0.377
0.309
0.24
0.172
0.104
0.035
Min: 3.505e19

As diffusion in Ni_2Si: simulation

Blum *et al* JAP 2008

Comparison to SIMS depth profiles

- Simulations can accurately fit the measured profiles

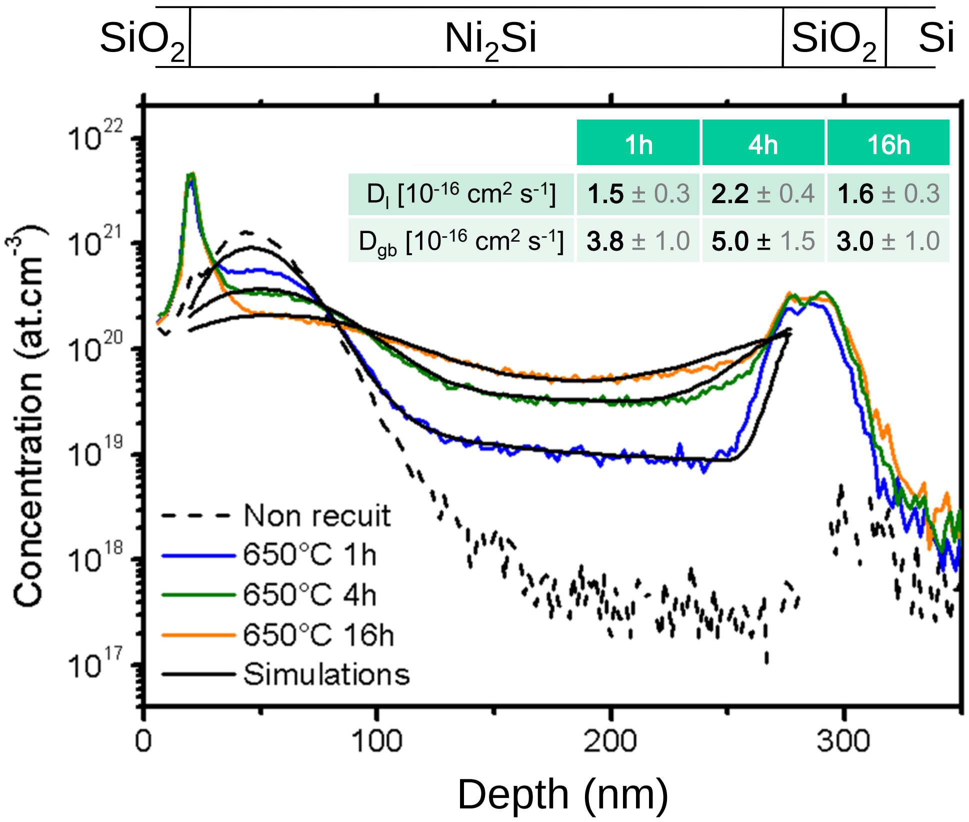
- Concentration is usually overestimated close to the bottom interface : Di is set to a too high value

- The peaks at the interfaces are not observed

→ Effect of segregation + SIMS matrix effects – not taken into account

- Measured coefficients do not depend on time

→ no transient enhanced diffusion



	1h	4h	16h
D_l [10^{-16} cm^2 s^{-1}]	**1.5** ± 0.3	**2.2** ± 0.4	**1.6** ± 0.3
D_{gb} [10^{-16} cm^2 s^{-1}]	**3.8** ± 1.0	**5.0** ± 1.5	**3.0** ± 1.0

Model can fit the measured profiles → measurements at different temperatures...

As diffusion in Ni_2Si: diffusion coefficients

Blum *et al* JAP 2008

Heat treatment at different temperatures: T° = 550 to 700°C, t = 1 to 186 h

- Lattice diffusion: D_{0l} = 1.5 10^{-1} cm^2/s, E_l = **2.7 eV** ±0.1
- GB diffusion: $D_{0\ gb}$ = 1.8 10^5 cm^2/s, E_{gb} = **3.1 eV** ±0.15

→ higher activation energy for GB diffusion !!!

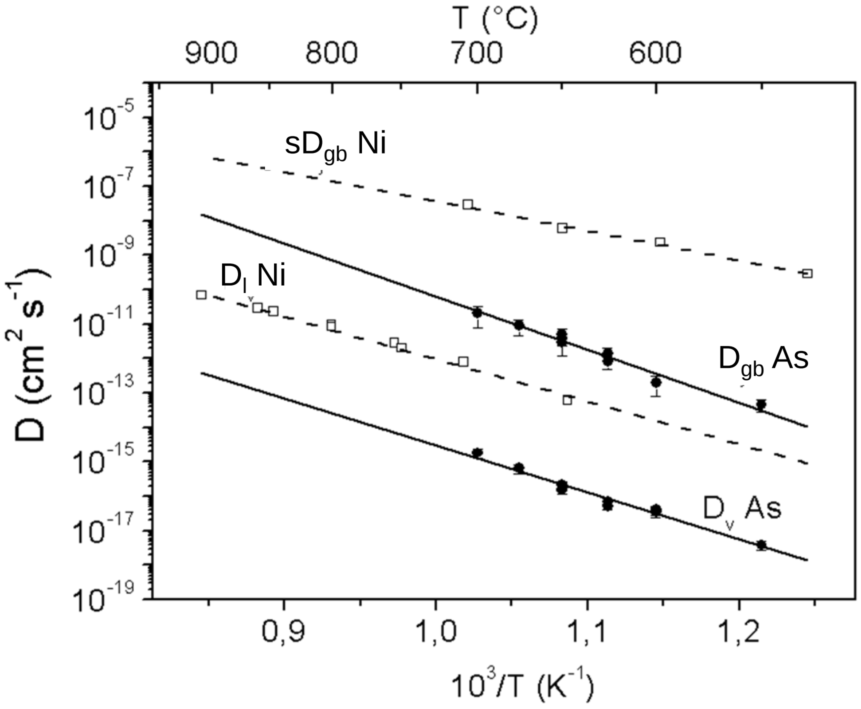
2 possible explanations :

1. Impurities segregated at the GBs could occupy the sites used by As for diffusion.

Low T° = High impurity segregation

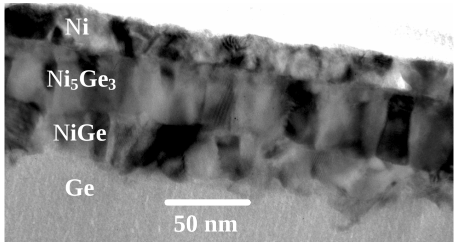
→ Low As diffusion

2. If Si segregates in Ni_2Si GBs, As would diffuse in Si rich GBs

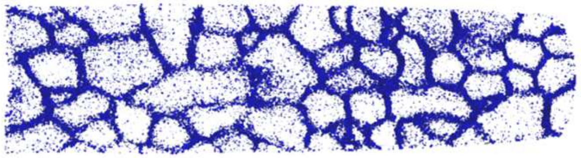


As in Ni_2Si lattice :	2.7 eV	→	Ni in Ni_2Si lattice :	2.6 eV
As in Ni_2Si GB :	3.1 eV		As in Si GBs :	3.4 eV

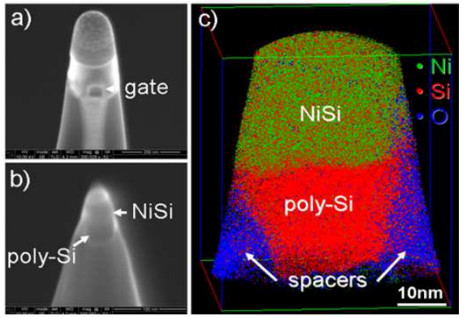
Reactive diffusion in microelectronics: outline



1. **Basis of reactive diffusion**
    - a) Diffusion couple / thin films
    - b) First stages : nucleation and lateral growth
    - c) Deal & Grove law and silicides
    - d) Sequential growth –simultaneous growth
    - e) Role of grain boundaries

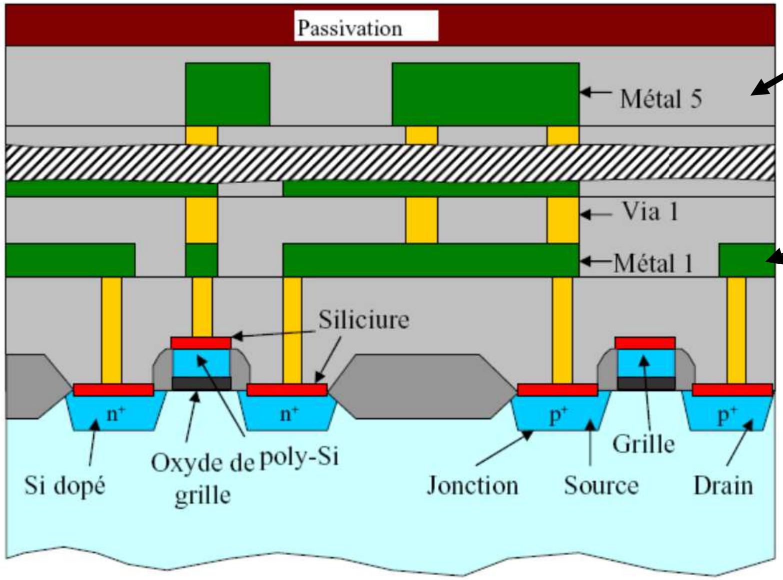


2. **Typical example : silicides in microelectronics**
    - a) Contacts in microelectronics
    - b) Analyses of transistors by atom probe
    - c) Nucleation and alloy effect



3. **Challenges**
    - a) Encroachment / transient phase
    - b) Nucleation / texture / stress
    - c) Doping / defects / dislocation / precipitation / redistribution
    - d) Nanoelectronics

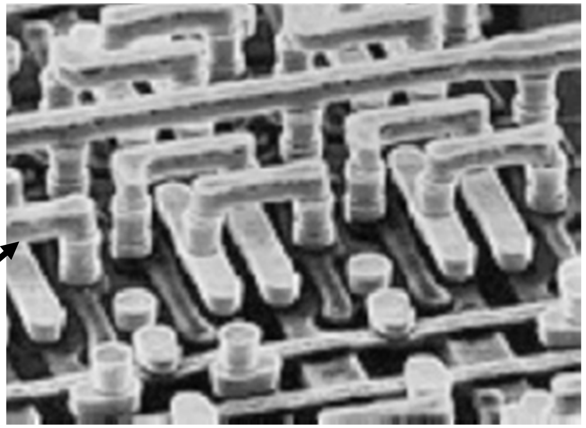
Reactive diffusion : silicides in microelectronics



Insulating material

Low-k

Metallic interconnections



Maier, G., *Progress in Polymer Science*, 26 (2001) 3

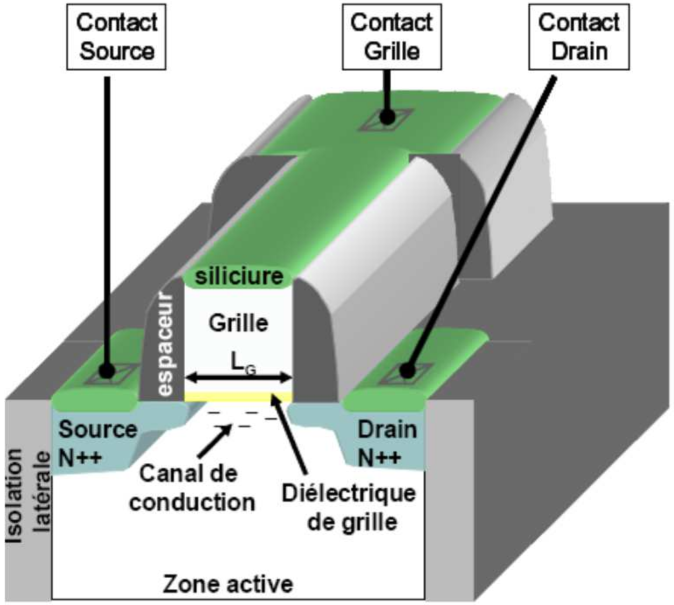
The integrated circuit is made of :

- active components
- metallic interconnections:

→Silicides used to reduce the contact resistance

→Silicide = larger contact area = low contact resistance

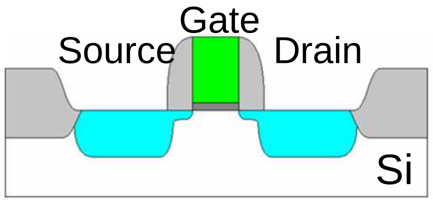
→Allows to spread the current along the active parts of the component



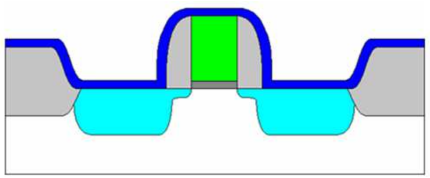
Fabrication : Salicide process

NiSi is now used for the high performance applications

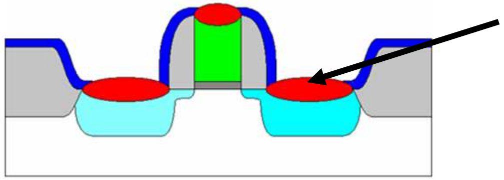
1) Predepostion cleaning



2) Metal deposition

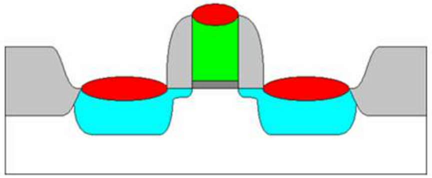


3) Rapid Thermal Anneal (RTA1)

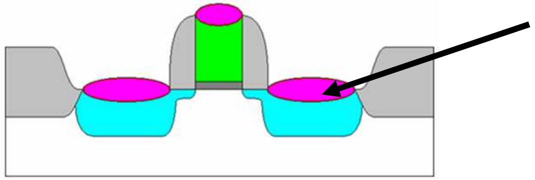


Ni$_2$Si + …

4) Metal selective etch



5) RTA2 : NiSi formation



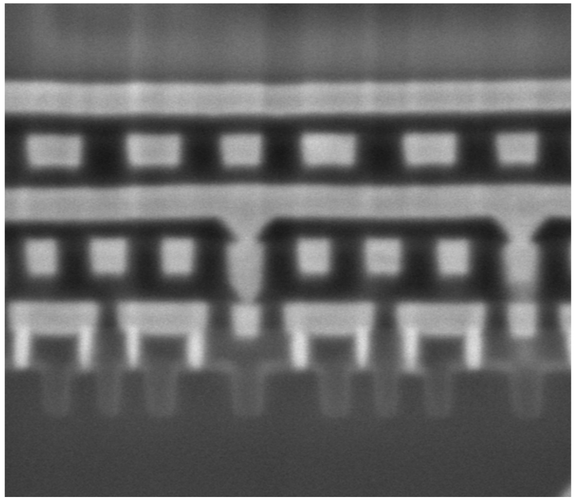
NiSi

Low resistivity

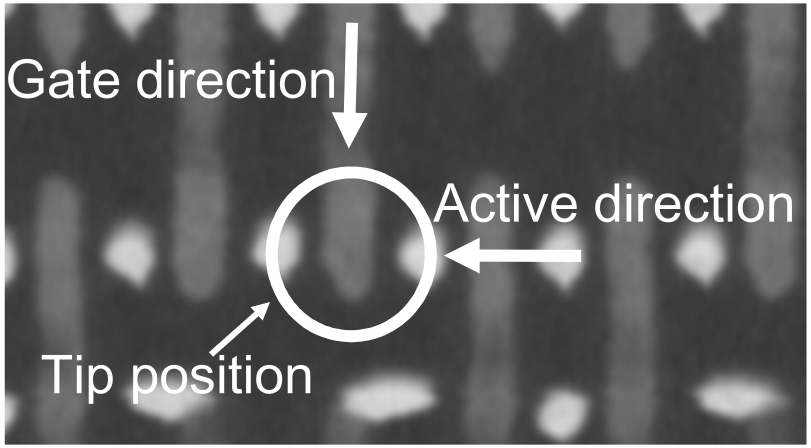
↳ Ni$_2$Si forms first and then reacts with Si to form NiSi

APT specimen fabrication by FIB

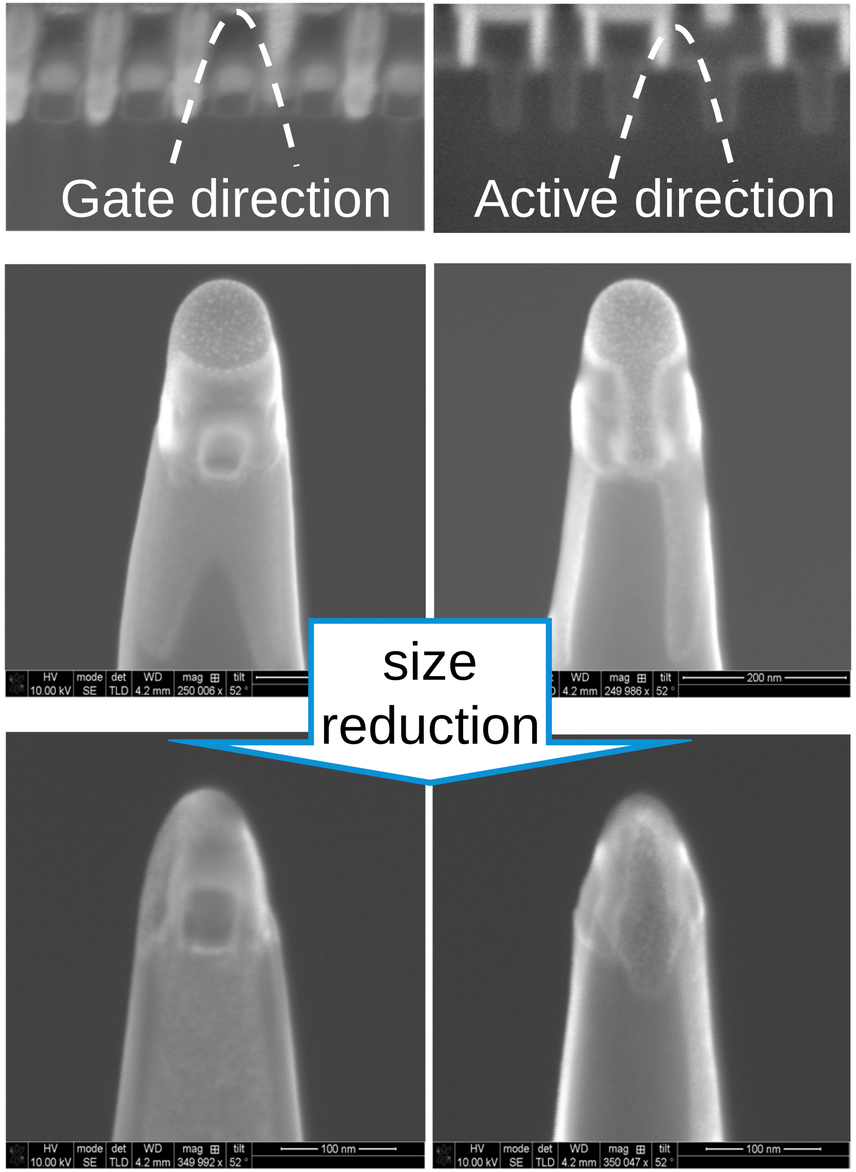
SRAM



Plan view of deprocessed SRAM



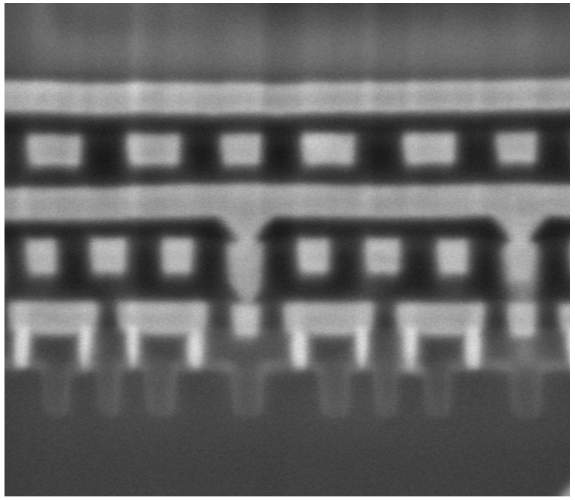
Cross section



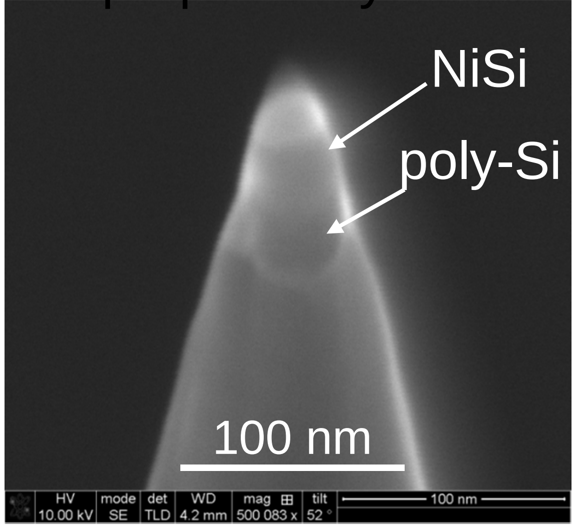
APT analysis of transistor

[F. Panciera et al. APL 99 (2011)]

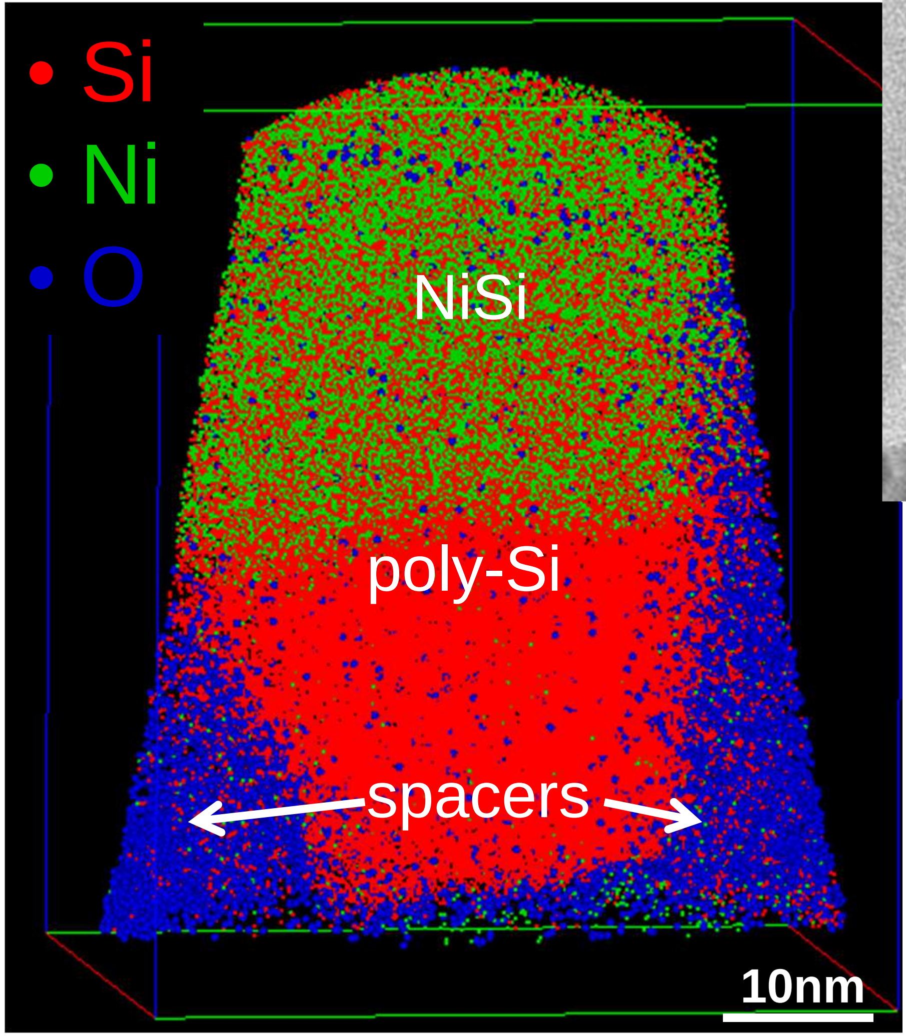
SRAM

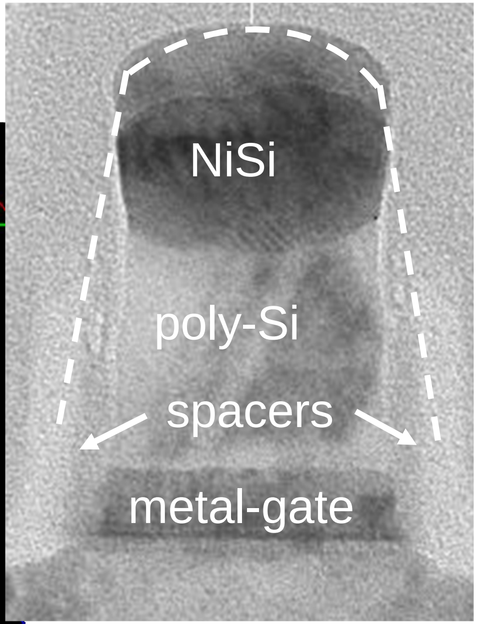


APT specimen
prepared by FIB



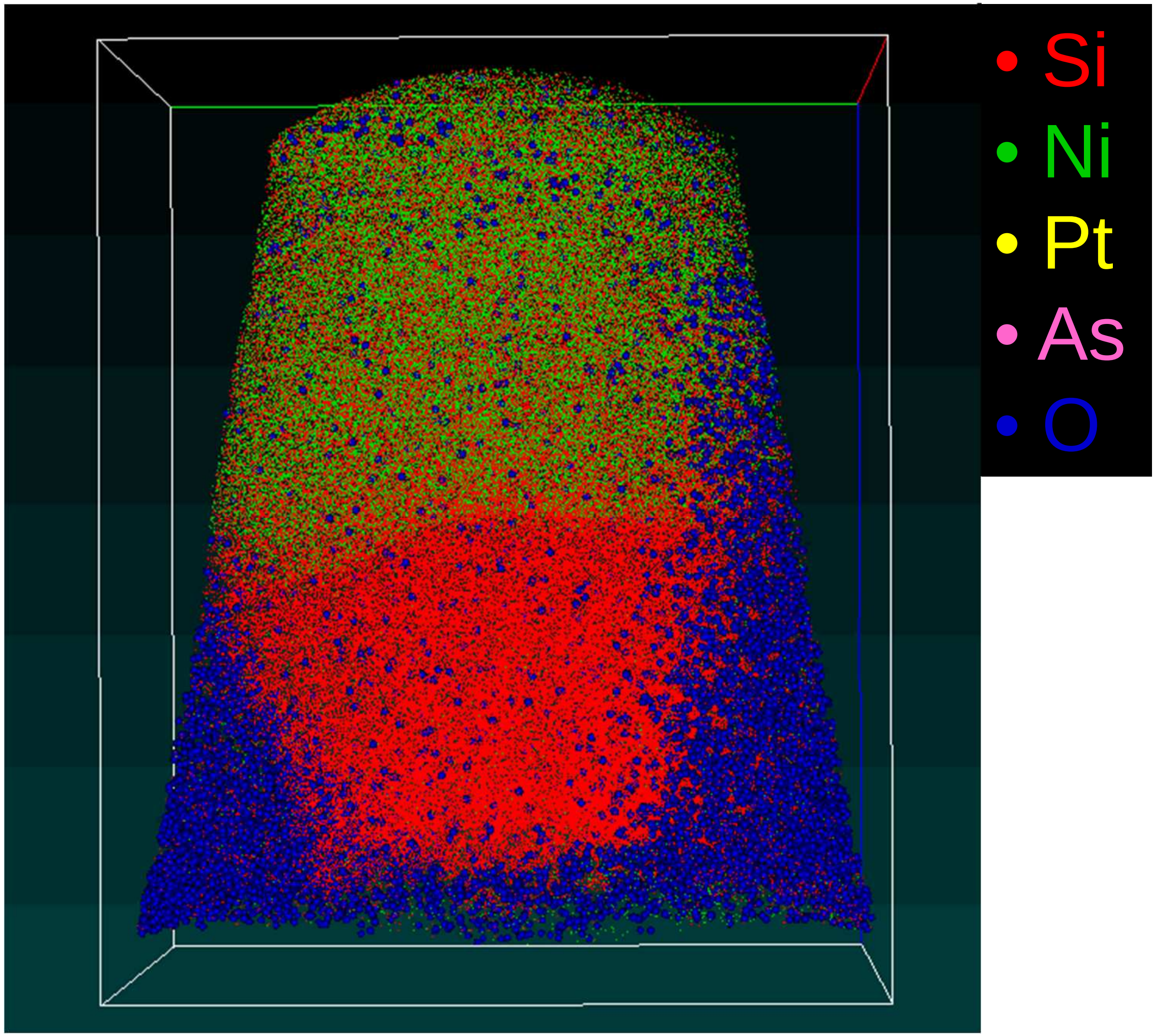
3D reconstructed volume





LEAP 3000X HR
(λ= 532 nm)

APT analysis of transistor: 3D



Enhanced stability of NiSi films on Si by addition of Pt

•Pb: Interface NiSi/Si not stable

→Nucleation of $NiSi_2$ à 750°C

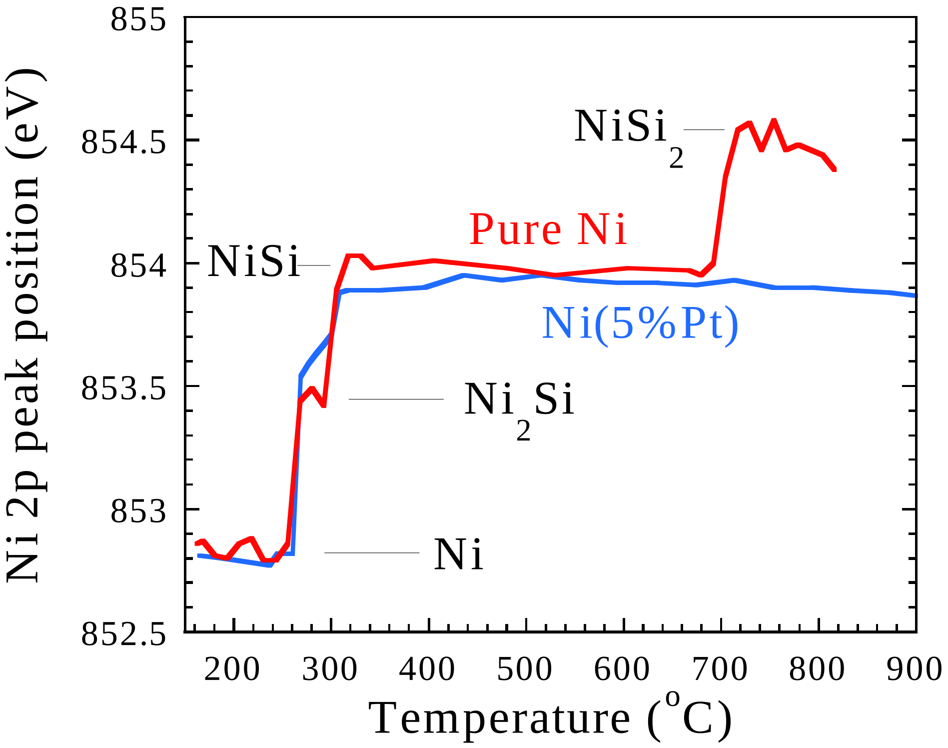
→Alloy element (Co, Pt, Pd, Au)

Experiments

→ Deposition of thin films of Ni with 5 at% Pt on Si substrate.

→ Characterization by RBS, SIMS, Micro Raman, XRD, XPS, …

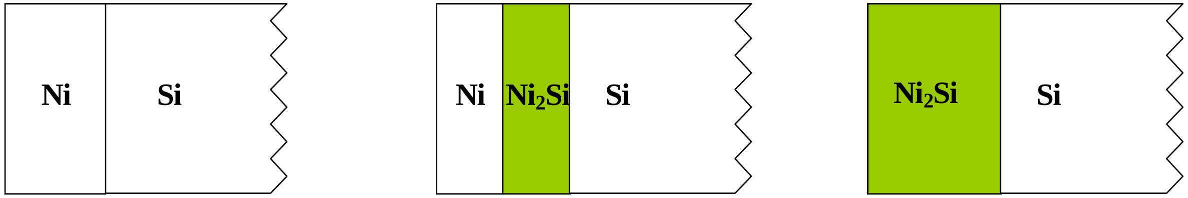
→The addition of Pt increase the thermal stability of NiSi



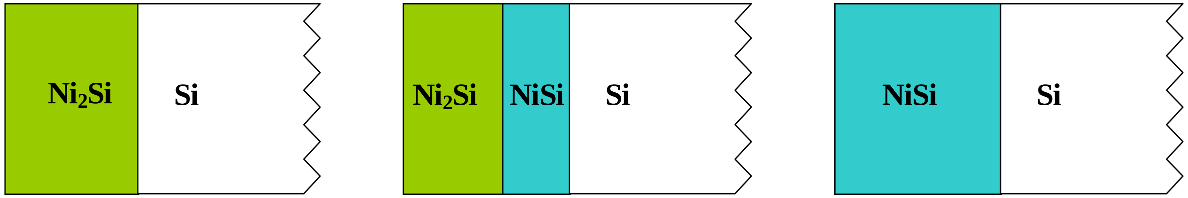
In situ annealing in a XPS system (Mangelinck et al, APL, 1999)

Reaction of Ni thin films with Si

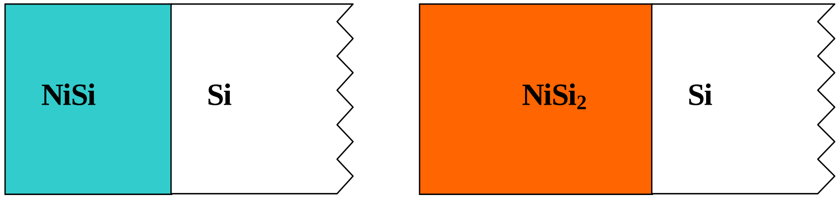
Submicron thickness
- **sequential formation**
- **3 phases: Ni_2Si, NiSi, $NiSi_2$**
- **diffusion of Ni**



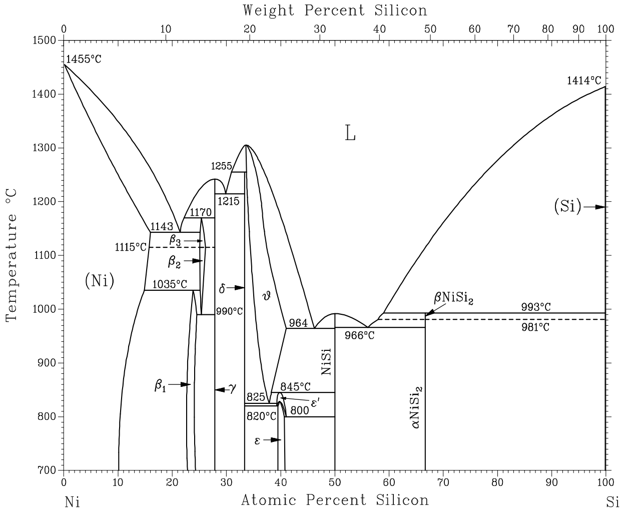
T ~ 200-300°C : formation of Ni_2Si : DIFFUSION controlled , Ni diffusion



T ~ 250-350°C : formation of NiSi : DIFFUSION controlled , Ni diffusion



T ~ 750-800°C : formation of $NiSi_2$: NUCLEATION controlled , Ni diffusion



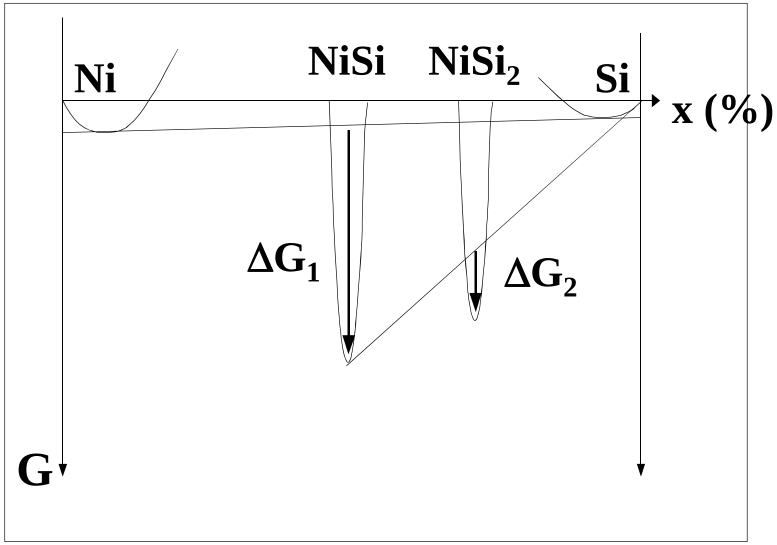
≠ Ni-Si phase diagram

Nanometric thickness

[Lavoie et al Microelec. Eng. 2003]
- **new phases?**
- **“transient” phases**
- **kinetic ?**

→Better understanding of the growth mechanisms

Enhanced stability of NiSi films on Si by addition of Pt



Nucleation barrier # $\Delta\sigma^3/\Delta G^2$

- $\Delta\sigma = \sigma(NiSi_2/Si) + \sigma(NiSi_2/NiSi) - \sigma(NiSi/Si)$
- $\Delta G = G_f(NiSi_2) - G_f(NiSi)$

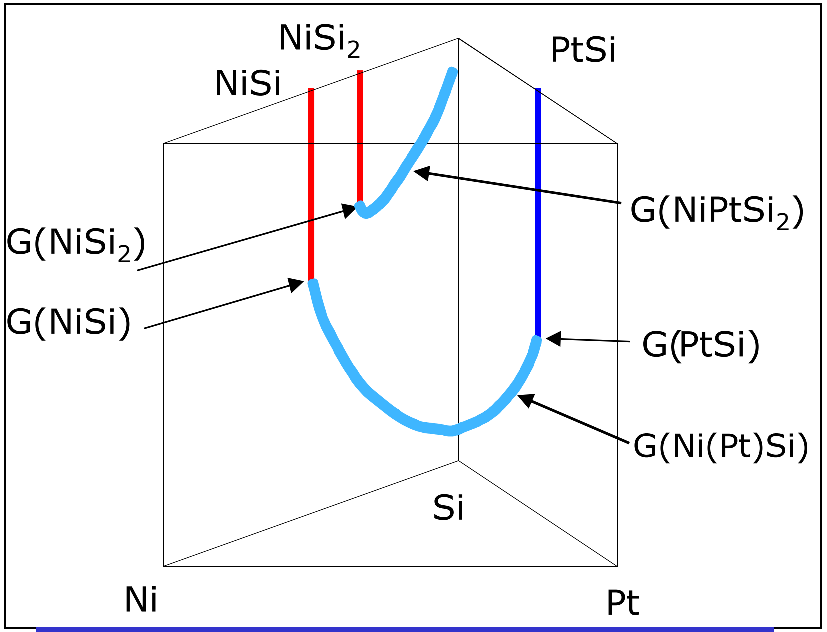
NiSi, PtSi: same structure, misfit<15%

- Total solid solution
- Decrease of Gibbs energy (G_f (NiSi))

Mixing entropy

→ Nucleation barrier

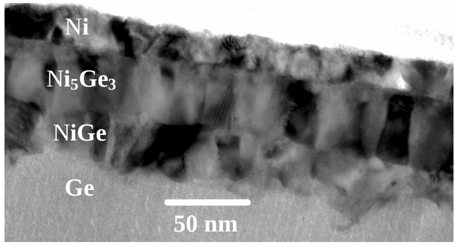
→ Ni(Pt)Si is now used in microelectronics



Schematic of the Gibbs free energy for the ternary system Ni-Pt-Si

D. Mangelinck, ANF Métallurgie, 22-25 octobre 2012, Aussois

Reactive diffusion in microelectronics: outline



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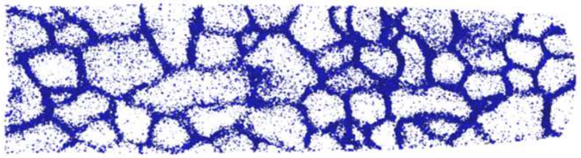

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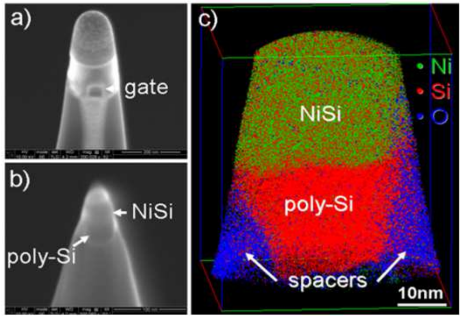
   a) Contacts in microelectronics
   b) Analyses of transistors by atom probe
   c) Nucleation and alloy effect

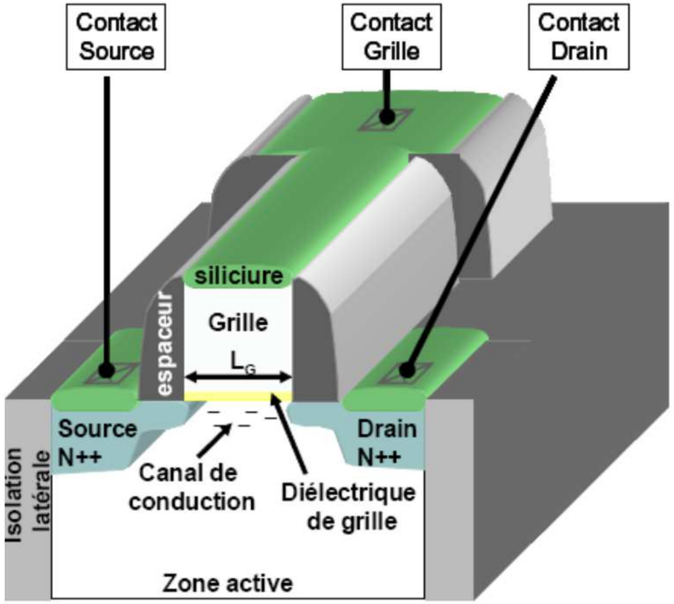


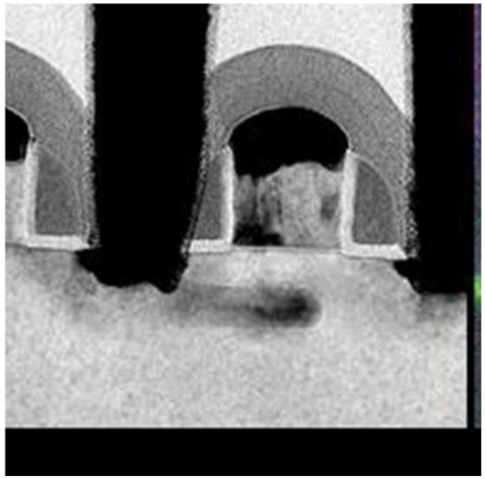
3. **Challenges**

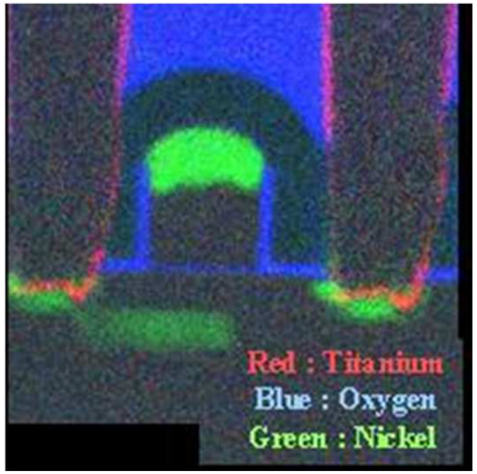
   a) Encroachment / transient phase
   b) Nucleation / texture / stress
   c) Doping / defects / dislocation / precipitation / redistribution
   d) Nanoelectronics

Silicides in microelectronics : reliability?

Ni(Pt)Si is now used for the high performance applications







Ideal structures → real structures

Reliability problems: → Encroachment or 'abnormal diffusion"

Parameters that lead to encroachment

- Stress/confinement
- Low thickness < 20nm
- Doping: N doping → As
- Effect of Pt

→ **transient phase ?**

Transient phase: definition

Lavoie et al, Microelec. Eng. 2003

Transient phase (TP) :

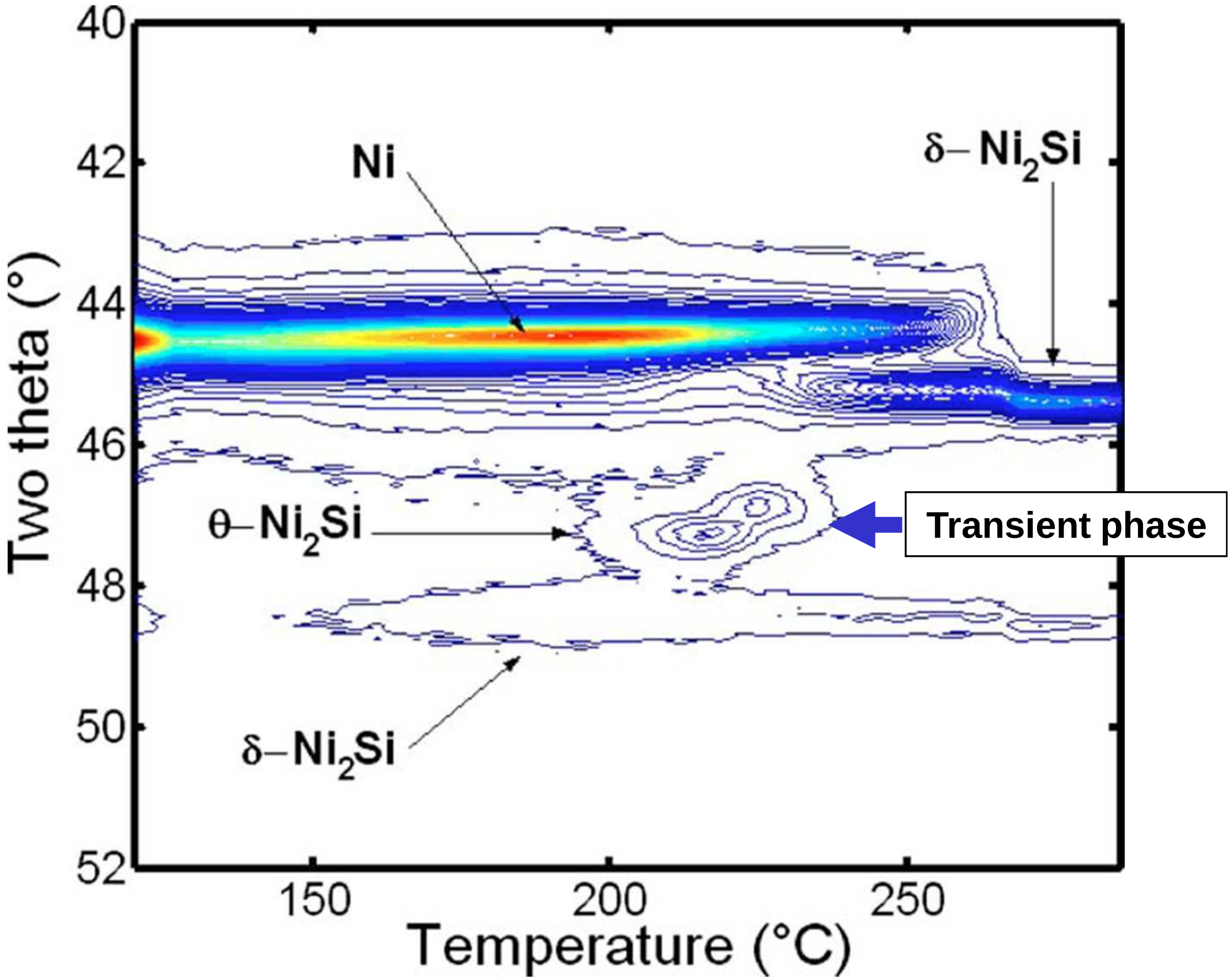
= unusual behaviour

- The end members (Ni and Si) are still present
- δ-Ni_2Si is growing
- The transient phase (θ-Ni_2Si) grows and shrinks during the growth of δ-Ni_2Si

≠ sequential growth

≠ simultaneous growth

Mangelinck et al, APL, 2009



In situ X ray diffraction of the Ni thin film reaction with a Si substrate

Transient phase: model

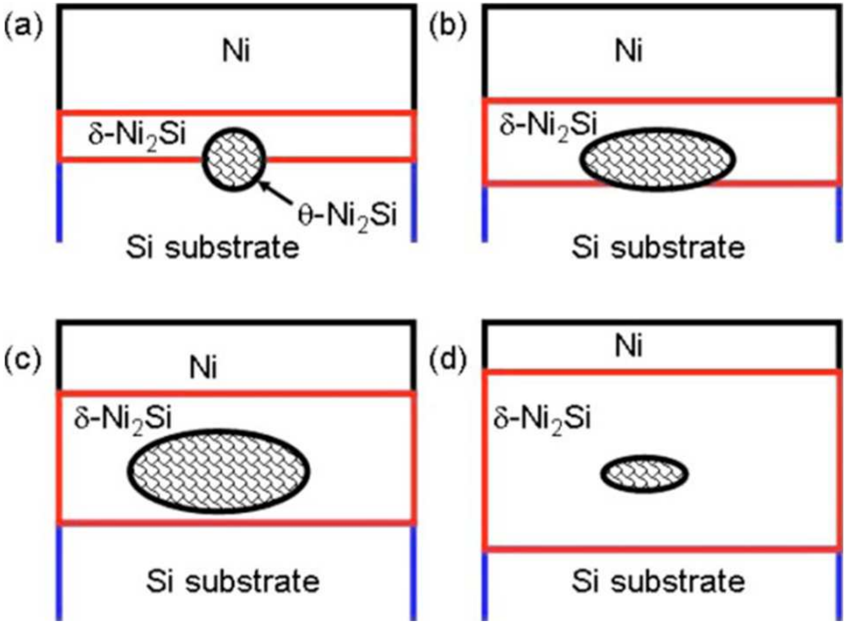
Mangelinck et al, APL, 2009

Possible scheme for transient phase (TP) :

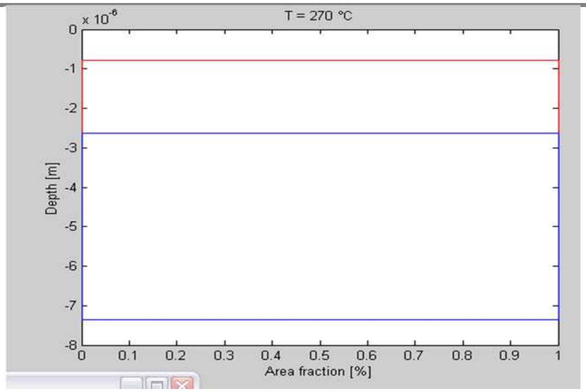
1 – lateral and normal growth of δ-Ni_2Si

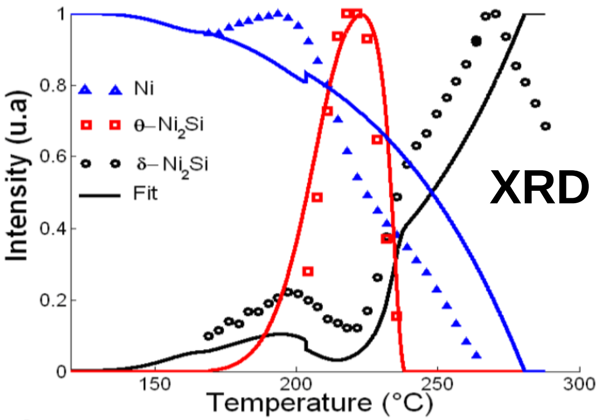
2 – nucleation and lateral growth of TP together with normal growth of δ-Ni_2Si

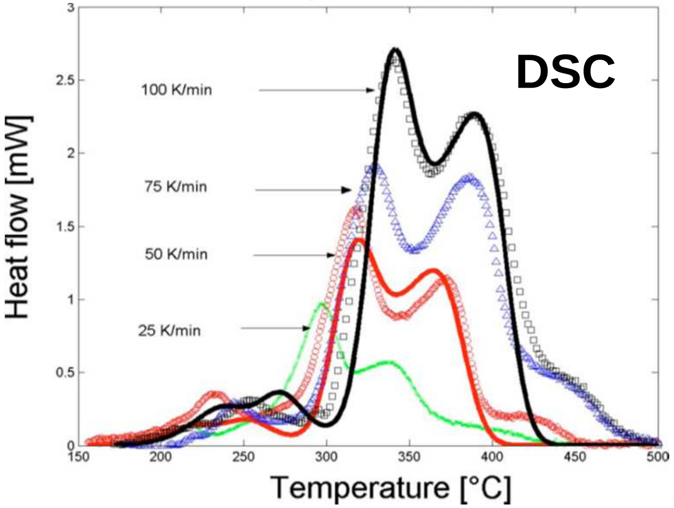
3 – shrinkage of TP when TP is enclosed by δ-Ni_2Si.



Model used to simulate DSC and XRD.

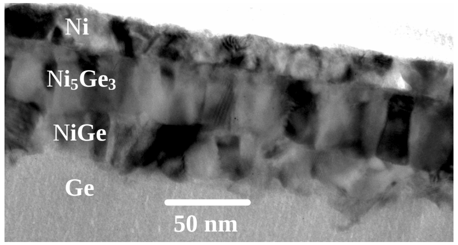


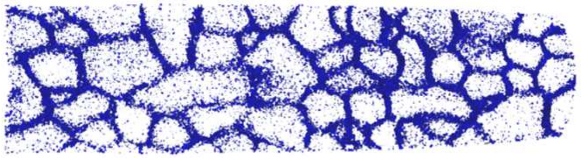




Reactive diffusion in microelectronics: outline

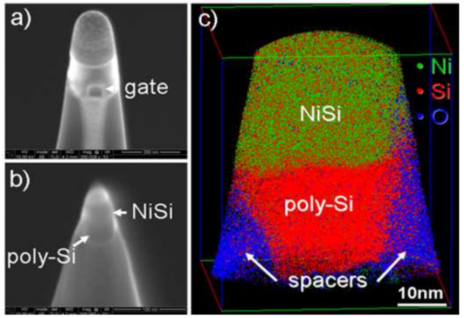
1. **Basis of reactive diffusion**
   a) Diffusion couple / thin films
   b) First stages : nucleation and lateral growth
   c) Deal & Grove law and silicides
   d) Sequential growth –simultaneous growth
   e) Role of grain boundaries





2. **Typical example : silicides in microelectronics**

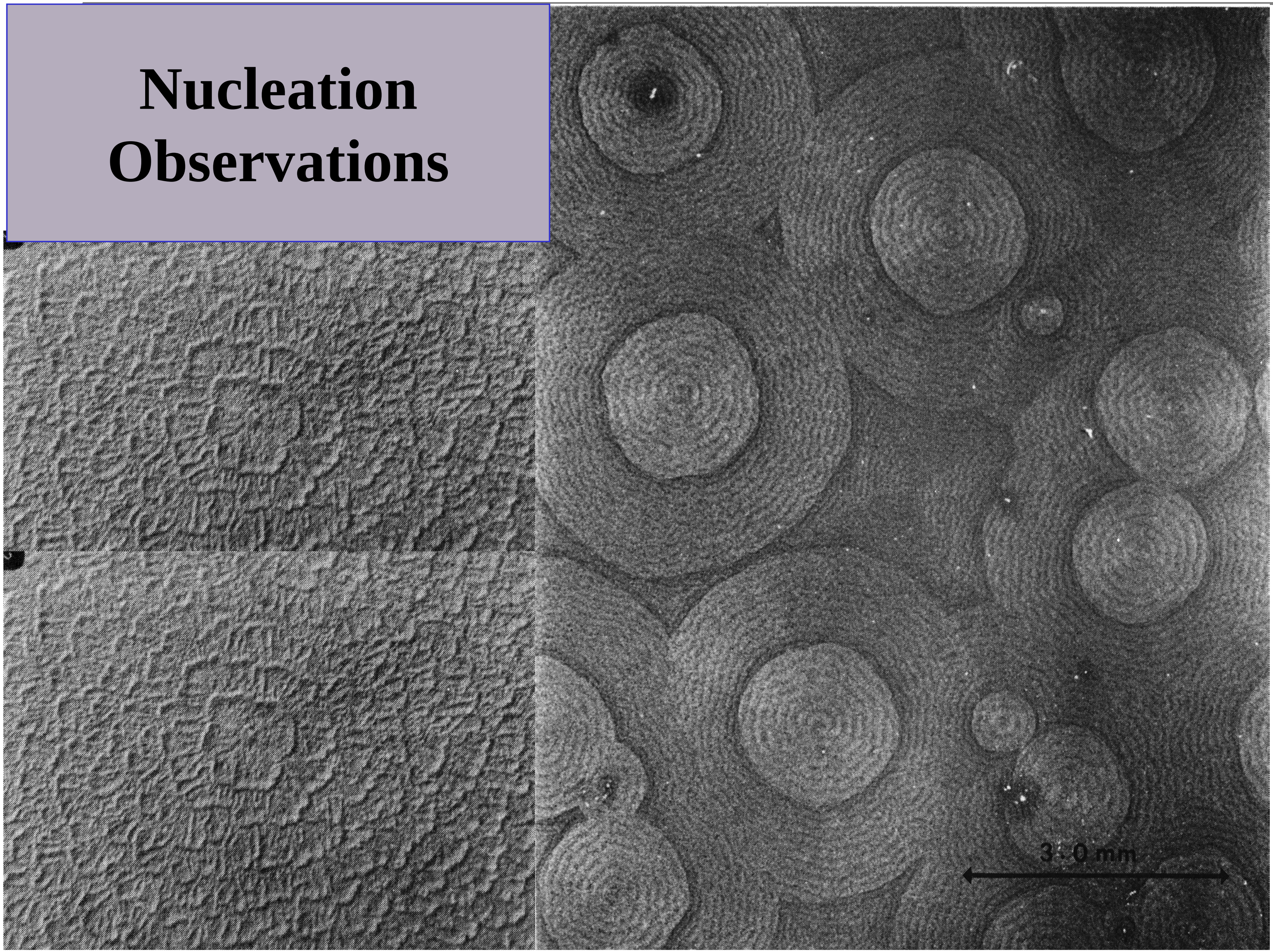
   a) Contacts in microelectronics
   b) Analyses of transistors by atom probe
   c) Nucleation and alloy effect



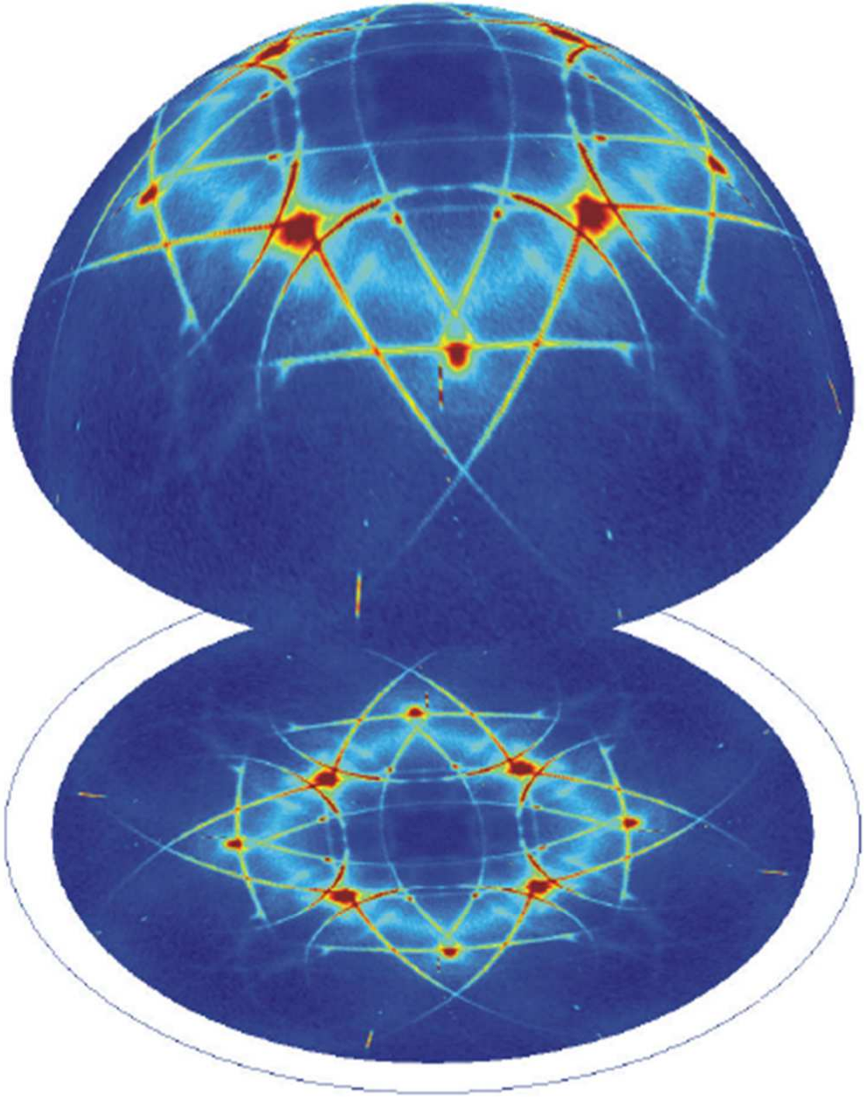
3. **Challenges**

   a) Encroachment / transient phase
   b) Nucleation / texture / stress
   c) Doping / defects / dislocation / precipitation / redistribution
   d) Nanoelectronics

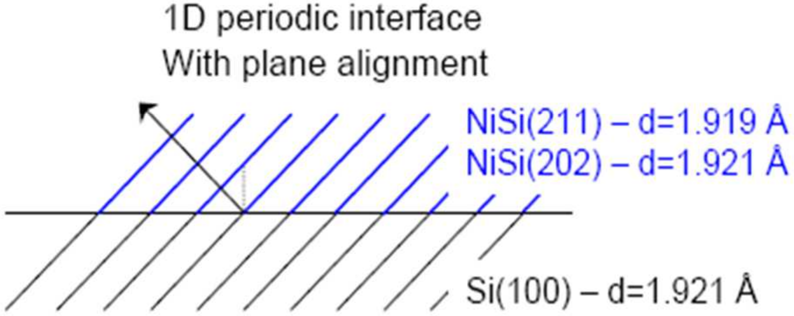
Nucleation Observations



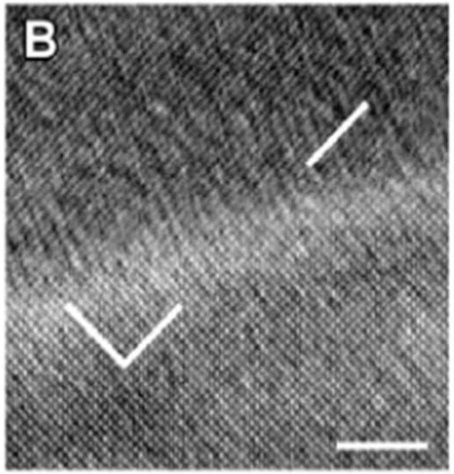
TEXTURE - Axiotaxy



(103) Pole Figure



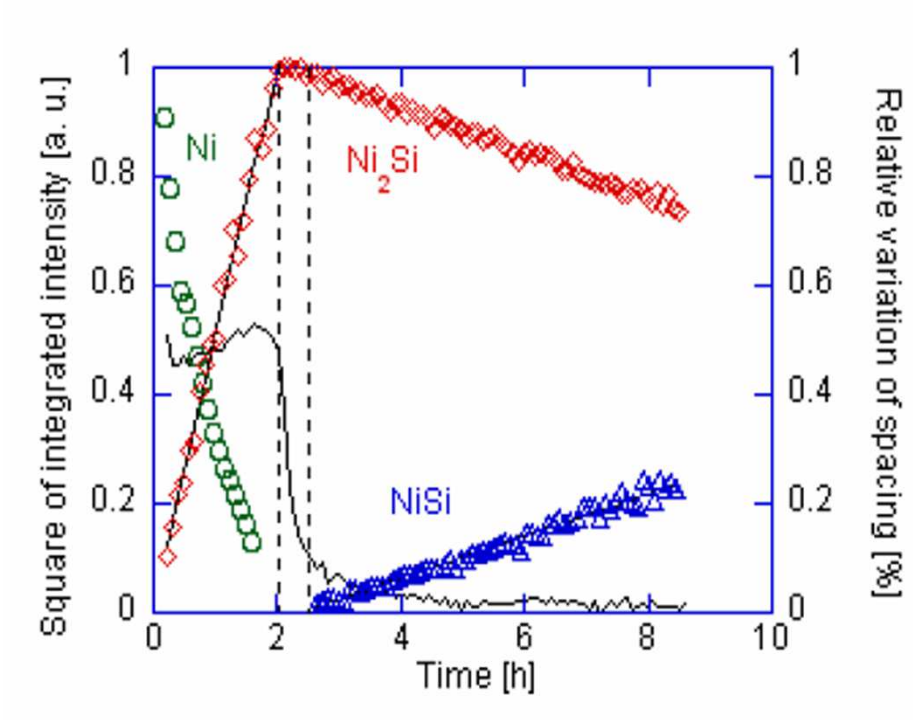
C. Detavernier, et. al., Nature **426**, 641 (2003)



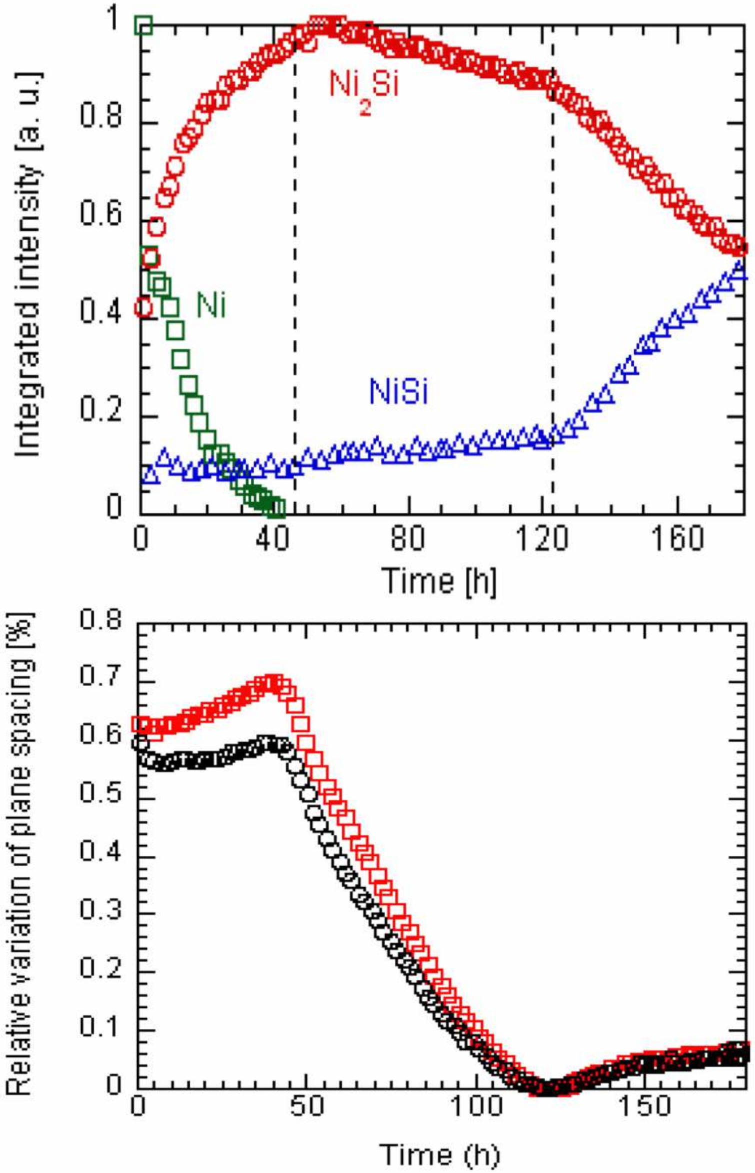
E.A. Stach,
National Center for Electron Microscopy,
LBNL, Berkeley, CA

Stress and silicide formation

Mangelinck et al, APL, 2008



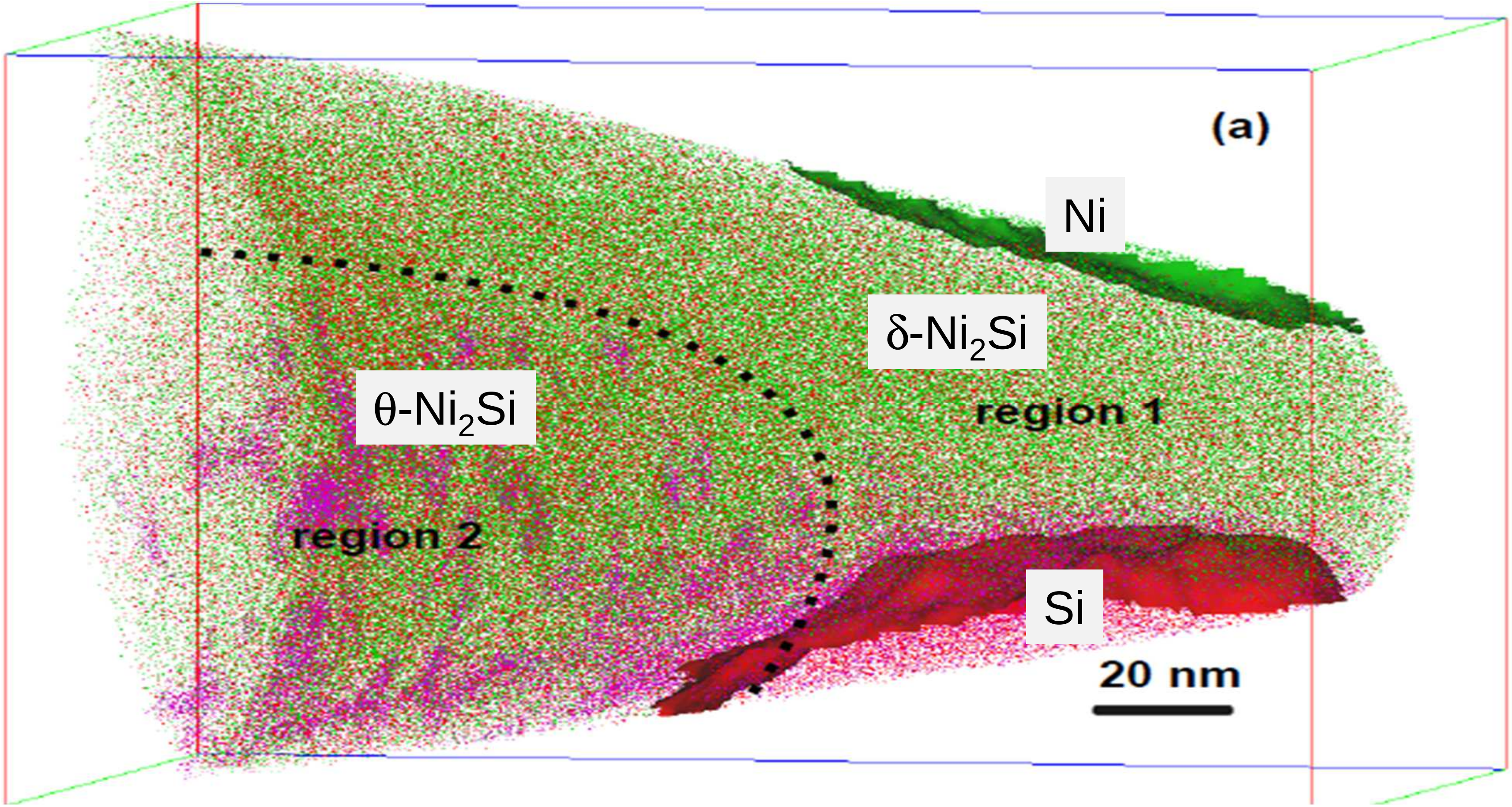
In situ XRD isotherm (210°C) of 50 nm Ni on amorphous Si



In situ XRD isotherm (210°C) of 50 nm Ni(5%Pt) on (100) Si

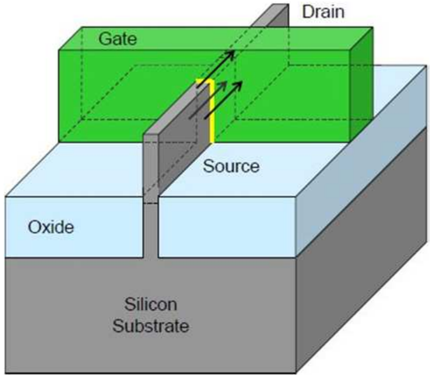
- ❑ Time delay (end of Ni_2Si - start of NiSi)
    - Nucleation ?
    - Strain/stress ?
- ❑ Ni(5%Pt)/(100)Si
    - Simultaneous growth of Ni_2Si/NiSi
    - Nucleation → **stress**

Dopants / defects / dislocation / precipitation / redistribution



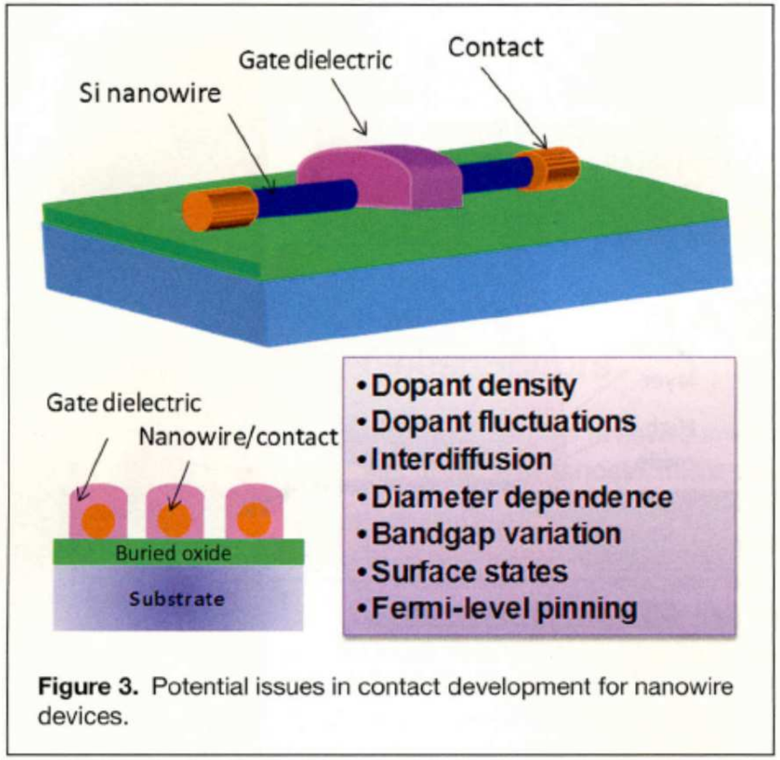
Precipitation of arsenic rich clusters at the grains boundaries of θ-Ni_2Si

Nanoelectronics: 3D structures, silicon nanowires…?



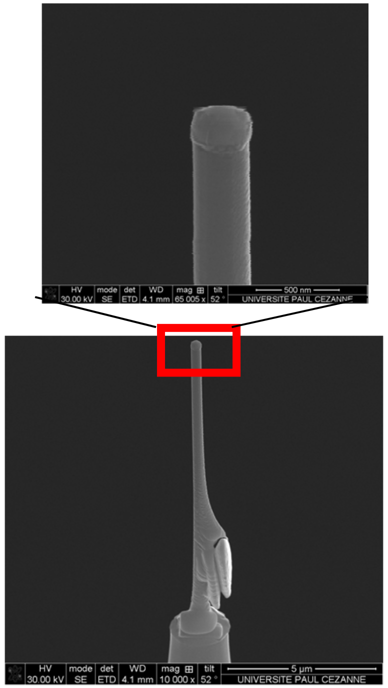
Tri-gate device

3D structures are replacing 2D planar structure in nanoelectronics

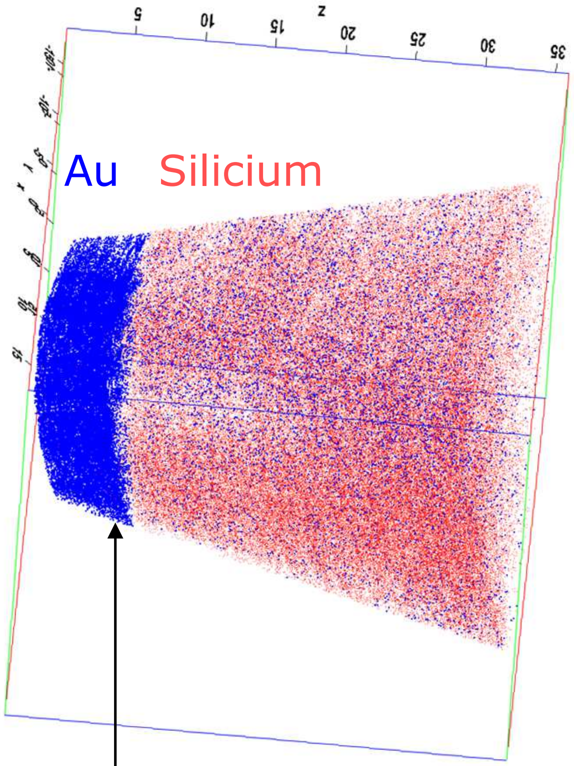


- Dopant density
- Dopant fluctuations
- Interdiffusion
- Diameter dependence
- Bandgap variation
- Surface states
- Fermi-level pinning

Figure 3. Potential issues in contact development for nanowire devices.



FIB Dual Beam



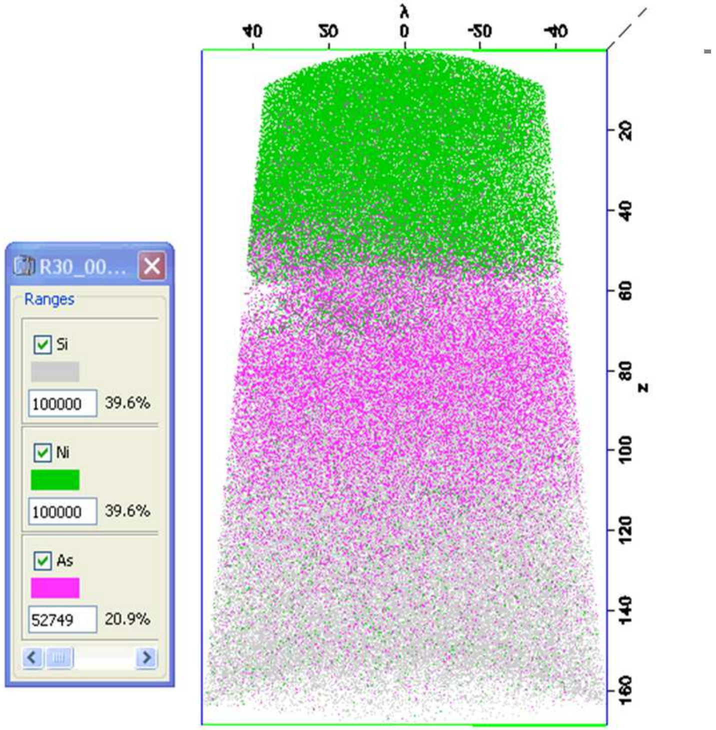
Interface Au / Silicium

mechanisms of growth, doping, metallization → metallurgy

Summary

Reactive diffusion in thin films

- Lateral and normal growth kinetics
- Nucleation
- Role of stress
- Role of grains boundaries / interface
- Sequential/simultaneous formation
- Transient phase / metastable phase
- Epitaxy/texture



The flying dislocation

Contact in microelectronics

- Salicide = complex interplay between defects, dopants and silicides
- Less than 10nm thickness in industry
  → ultra thin silicide (reactive diffusion? surface science?)
- Analysis of transistors by APT
- Thermal stability on Si, SiGe, Ge
- 3D structure / nanowires….