Redistribution of doping elements in SiGe nanostructures

J.P. Ayoub, I. Berbezier, A. Ronda, A. Portavoce

L2MP – CNRS, Polytech Marseille, 13451 Marseille – France

K. Lyutovich, M. Oehme, J. Werner, E. Kasper

Halbleitertechnik, Stuttgart, Germany

M. Berti, M. Di Marino, G. Bisognin, E. Napolitani

MATIS-CNR-INFM, Dip. di Fisica, Università di Padova, ITALY

Laboratoire Matériaux et Microélectronique de Provence

OUTLOOK

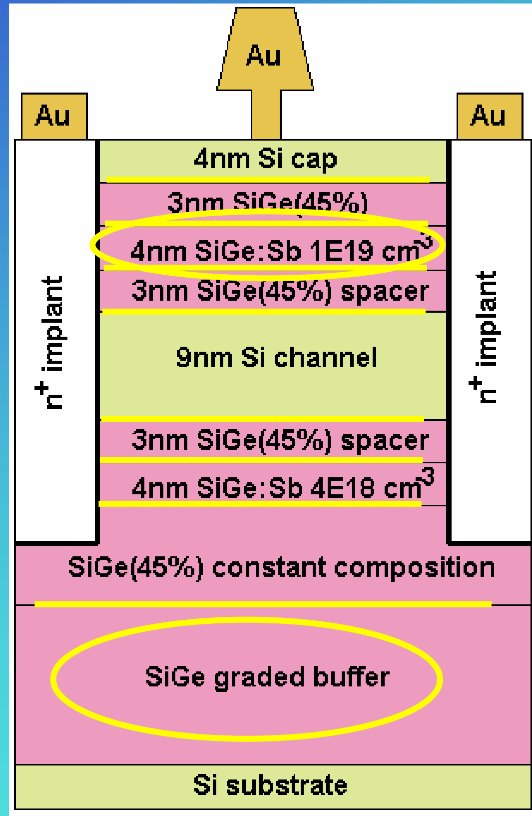
- Context of the study
- Experimental procedure
- Results :
  - Segregation of Sb at L.T.
  - Segregation of Sb at H.T.
- Conclusion

Aim : SiGe MODFET

type n

Si channel

(tensile strain)



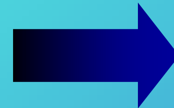
type p

Ge channel

(compressive strain)

Requirements

- SiGe layers with high Ge content
- High level of doping ~ $10^{19}/cm^3$
- Abrupt interfaces



Problems

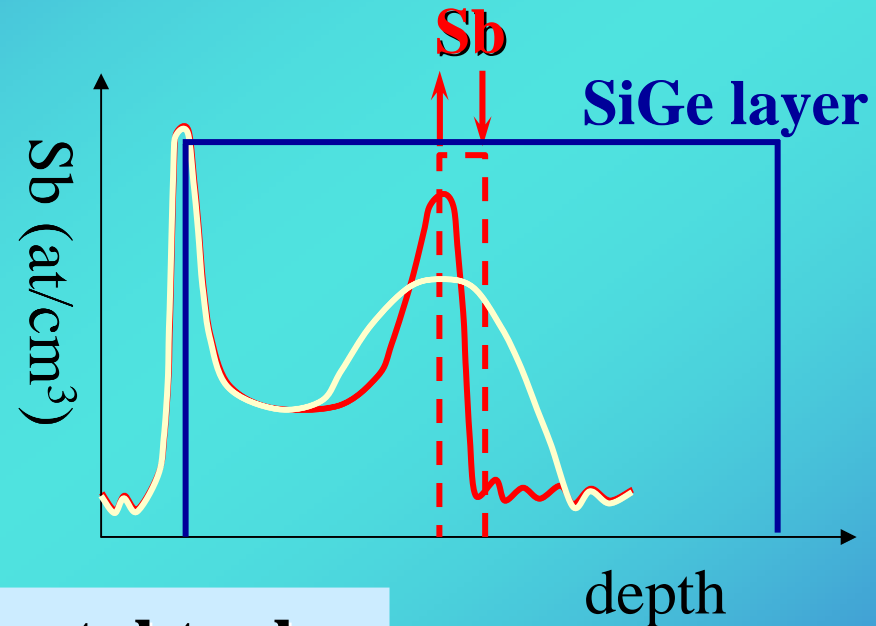
- Relaxed buffer layers
- Redistribution of dopants

  Effect of stress

  Effect of Ge content

Investigation of dopant (Sb) redistribution in SiGe

- **Surface segregation**
- **Diffusion**



Experimental tools

Growth : SS-MBE

Base pressure < 10^{-11} torr

Si ⇒ electron beam evaporator

Ge, Sb ⇒ Knudsen cells

Characterization

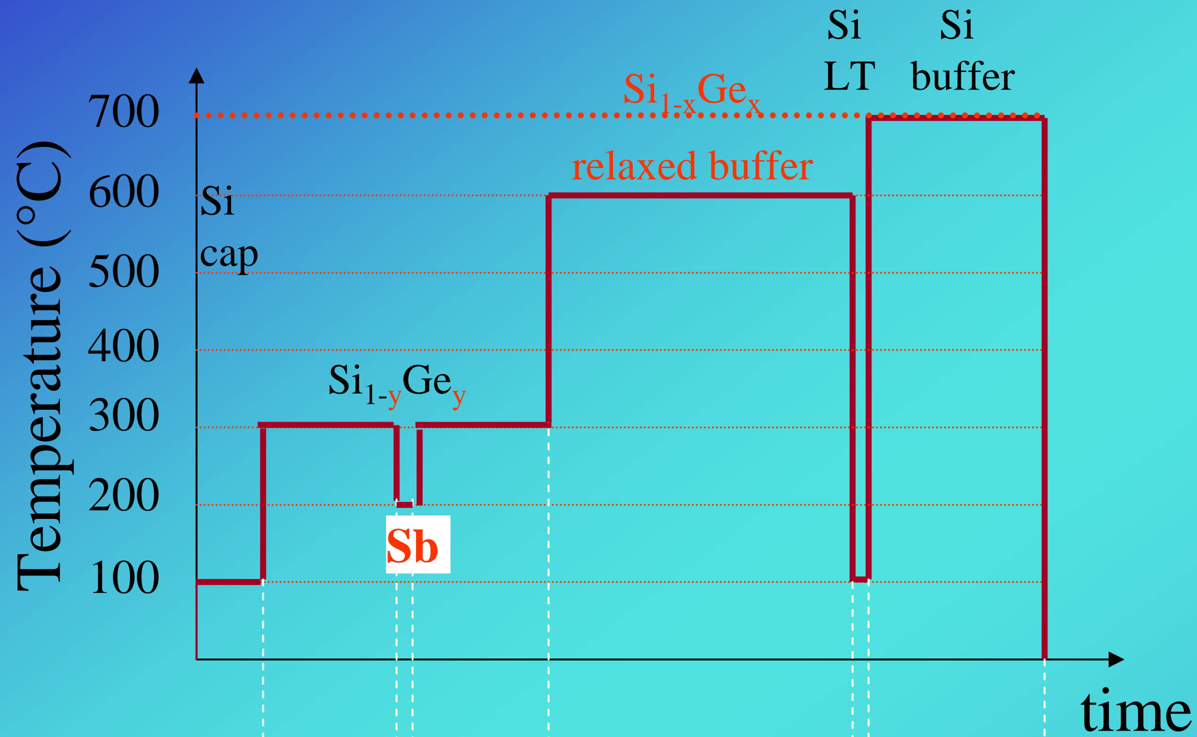
Stress relaxation, morphology (TEM)

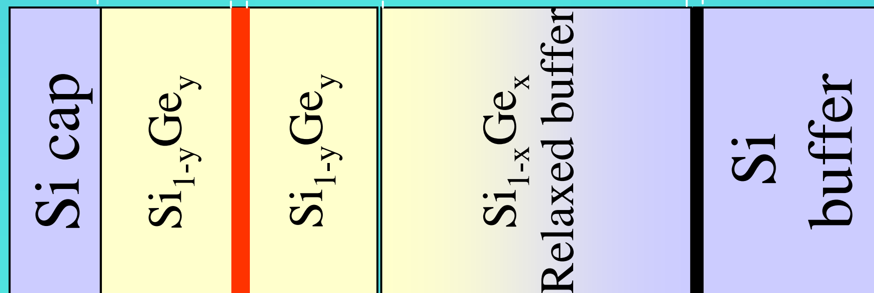
Sb depth profiles (SIMS simulations)

Ge concentration (RBS)

Strain of the SiGe layers (XRD)

Experimental conditions : segregation

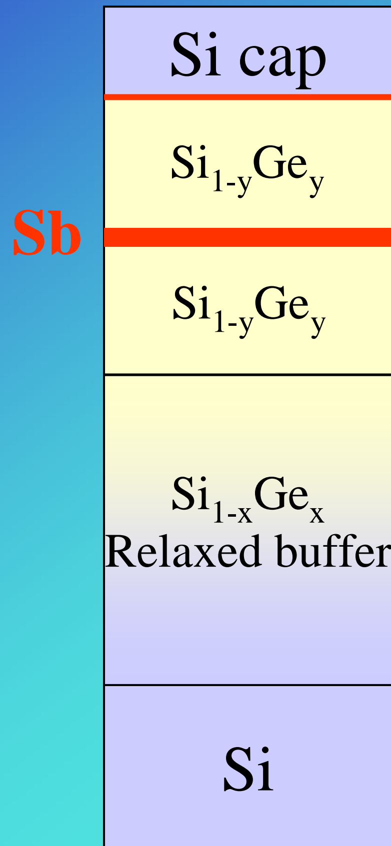


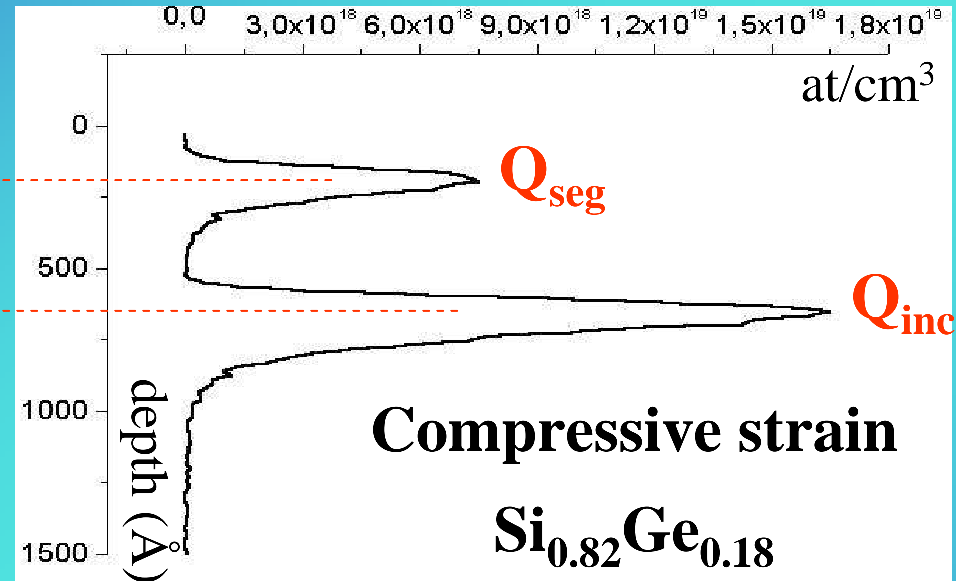


Effect of:

- temperature T_G
- Ge concentration (y)
- strain (x / y)

Variation of the biaxial strain





$y > x$ compressive strain
$y < x$ tensile strain
$y = x$ relaxed

Measurements:

- $r_{seg} = Q_{seg}/Q_{tot}$
- $r_{inc} = Q_{inc}/Q_{tot}$

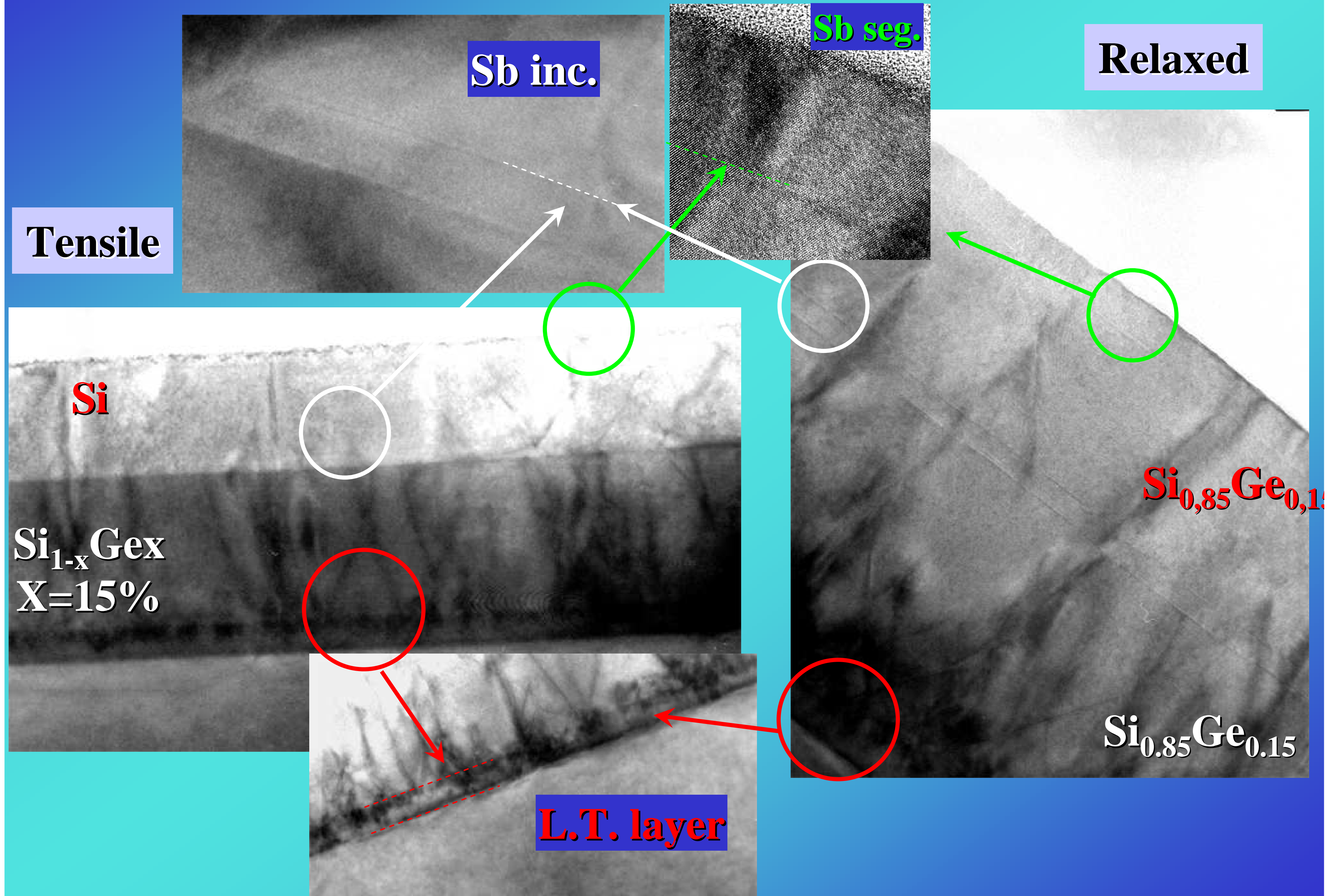
Fabrication of relaxed buffer layers

Compression

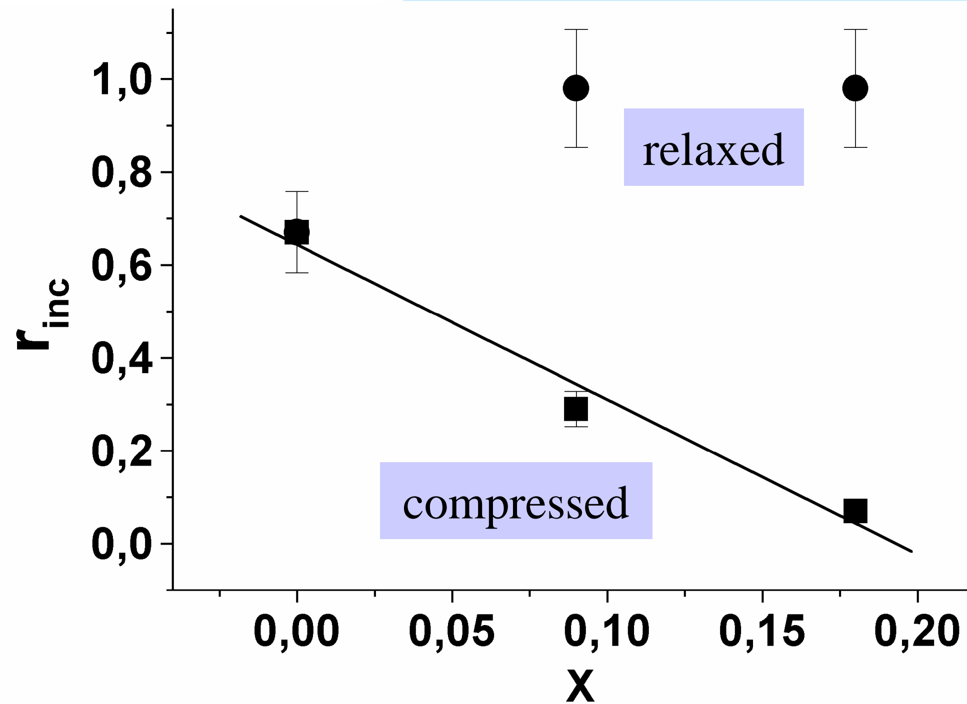
$Si_{0,82}Ge_{0,18}$

$Si_{0,9}Ge_{0,1}$

Fabrication of relaxed buffer layers



T_G = 200 °C — Effect of strain and of Ge %



Segregation increases with compressive strain

Relaxed layers

x ⬀ ⇒ segregation ⬂

Epitaxial layers
Compressive strain

x ⬀ ⇒ segregation ⬀

P^b ⬀ ⇒ segregation ⬀

At low T_G :

	Strain state	Effect of	Sb
segregation	compressed	x ⇗	r_{seg} ⇗
	compressed	P^b ⇗	r_{seg} ⇗
	relaxed	x ⇗	r_{seg} ⇘
diffusion	compressed	x ⇗	D^{Sb} ⇗
	compressed	P^b ⇗	D^{Sb} ⇗
	relaxed	x ⇗	D^{Sb} ⇗

⇨ **Effect of stress : r_{seg} follows D_{Sb}**

⇨ **dominated by kinetic diffusion**

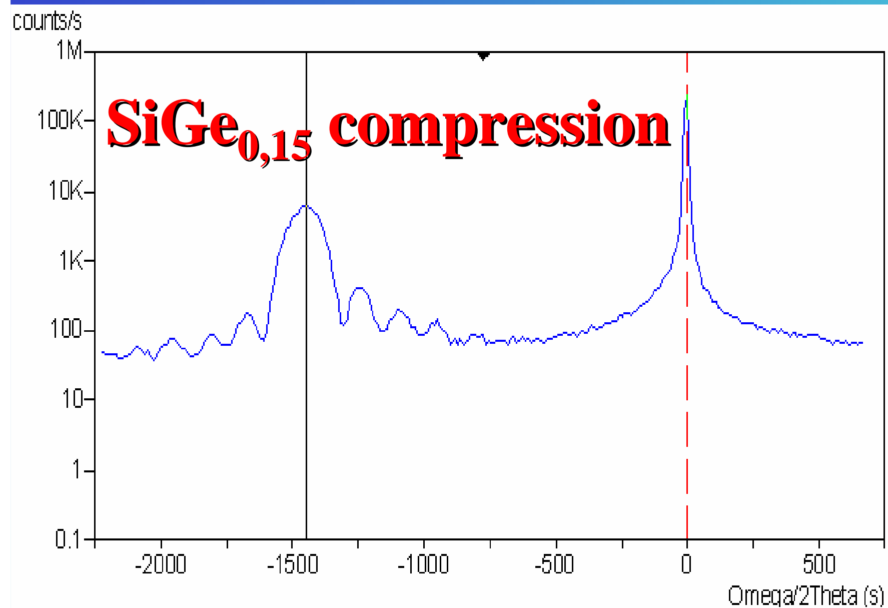
⇨ **Effect of Ge content : r_{seg} evolution is opposite to D_{Sb}**

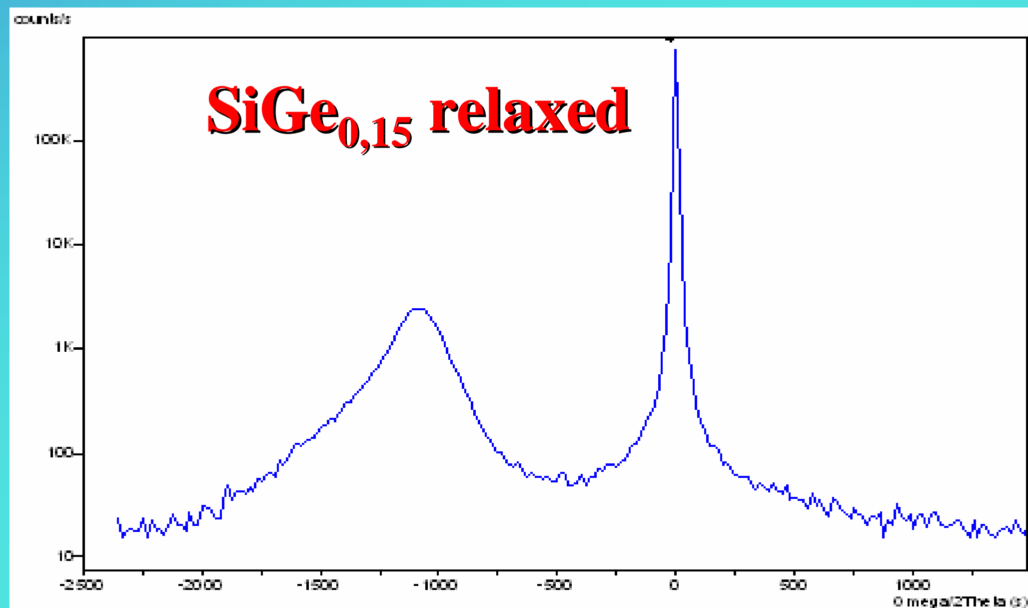
⇨ **equilibrium segregation**

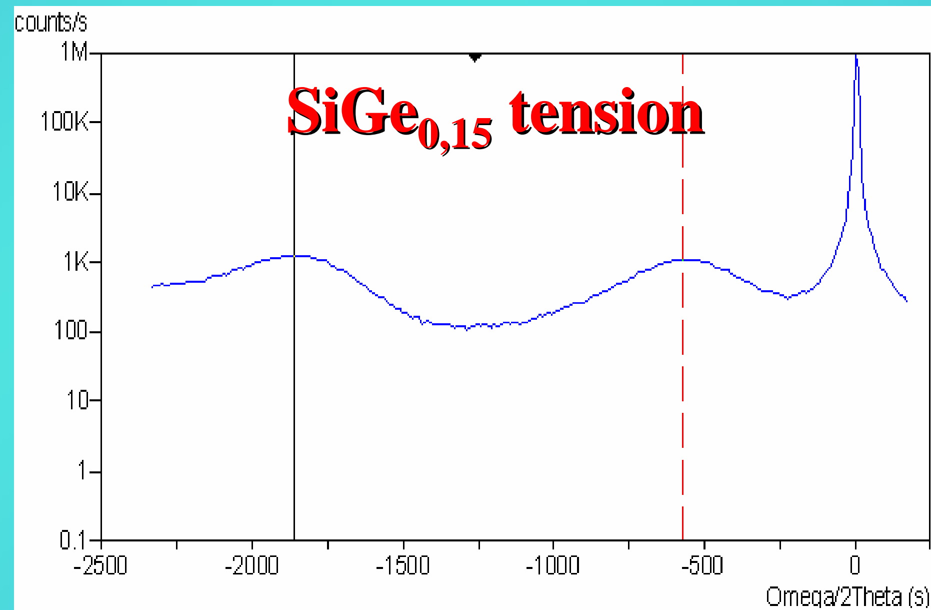
At high T_G :

Active layer	T_g °C	Ge % buffer	Ge % layer	Strain state
Si	380	16,5	0	**Tensile**
		0	0	**Relaxed**
$Si_{0,85}Ge_{0,15}$	350	33,3	16,4	**Compressed**
		14,5	14,5	**Relaxed**
		0	15,2	**Tensile**
$Si_{0,3}Ge_{0,3}$	320	48,3	33,5	**Compressed**
		30	30	**Relaxed**
		15	32,3	**Tensile**
$Si_{0,5}Ge_{0,5}$	290	46,1	46,1	**Relaxed**
		35,2	49,9	**Compressed**

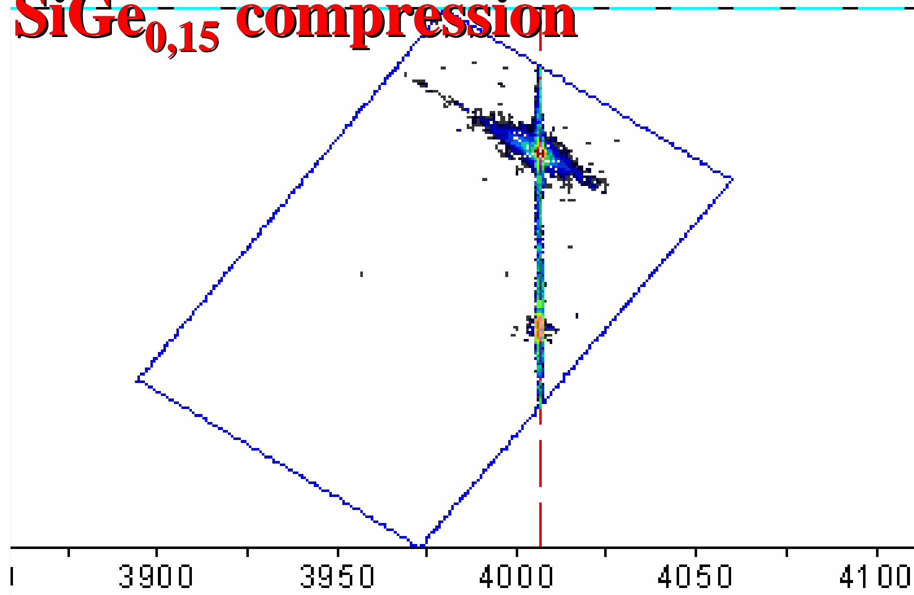
XRD Results

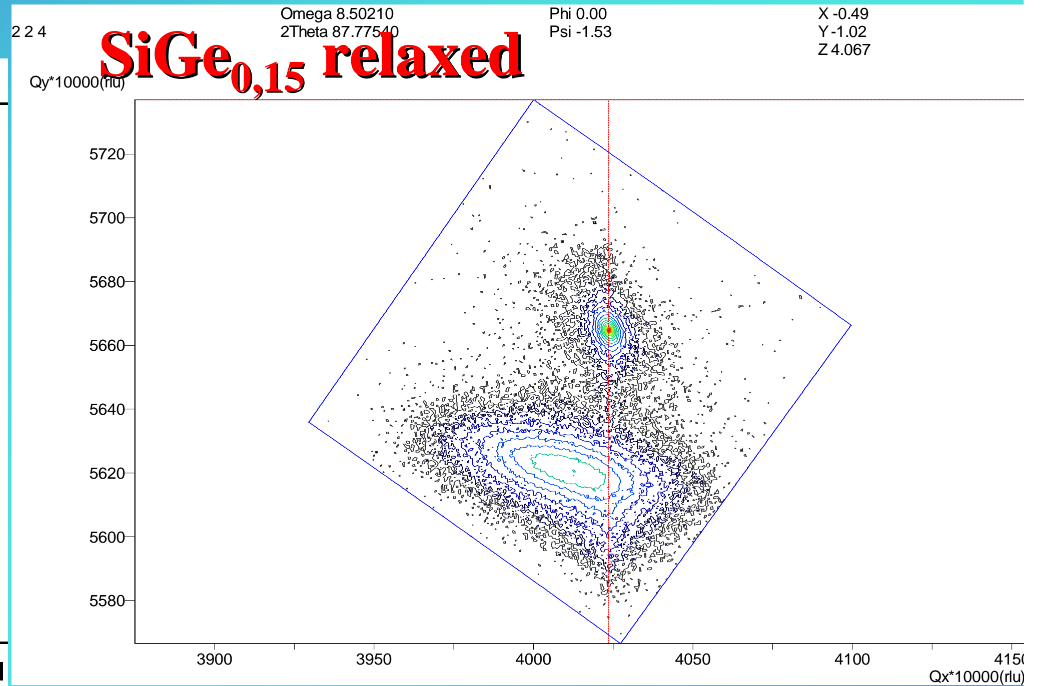


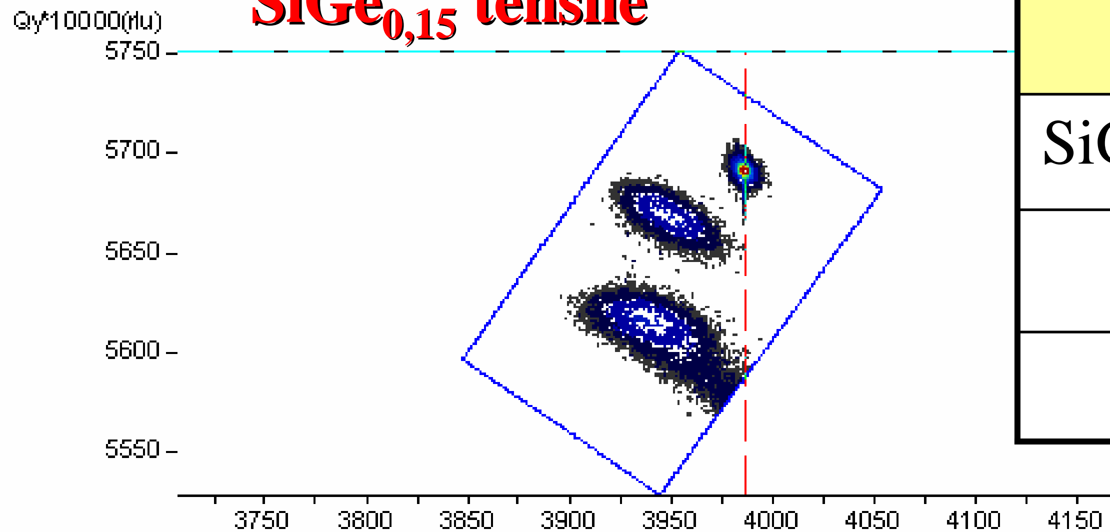




XRD Results

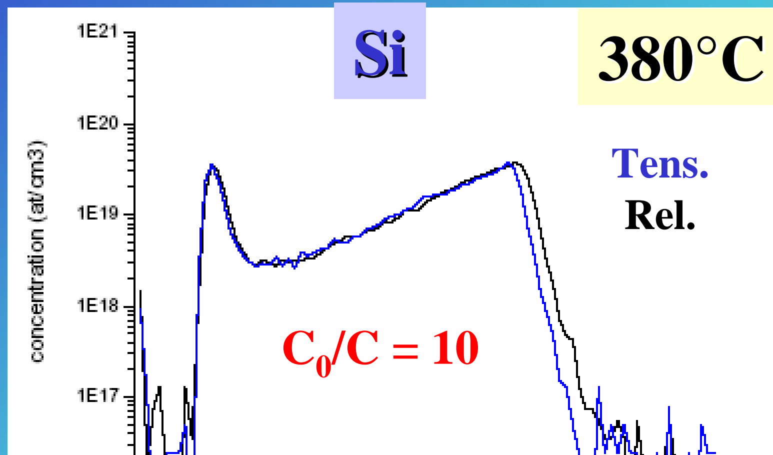


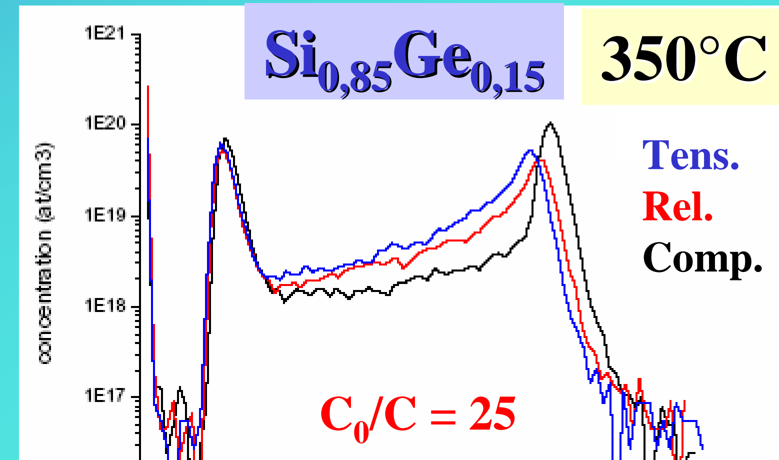




Nominal layer	$\varepsilon_{\perp}$
$SiGe_{0,15}$ compression	0,0045
$SiGe_{0,15}$ relaxed	0,002
$SiGe_{0,15}$ tension	- 0,0024

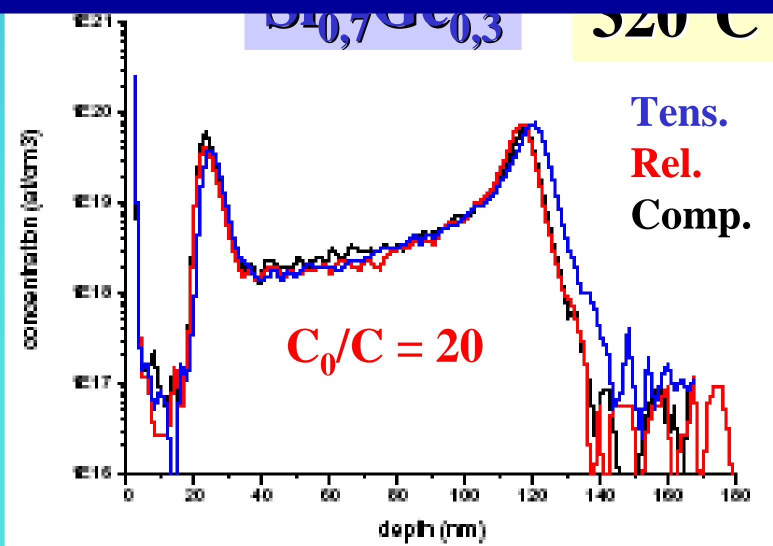
SIMS Profiles

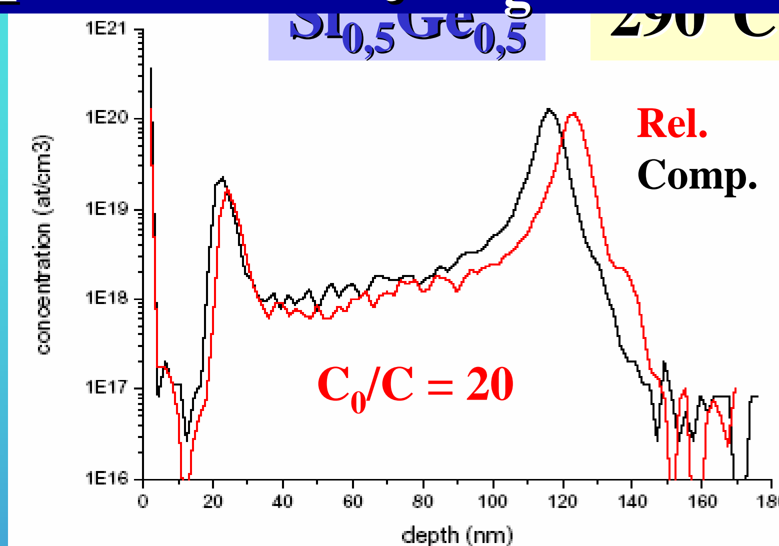




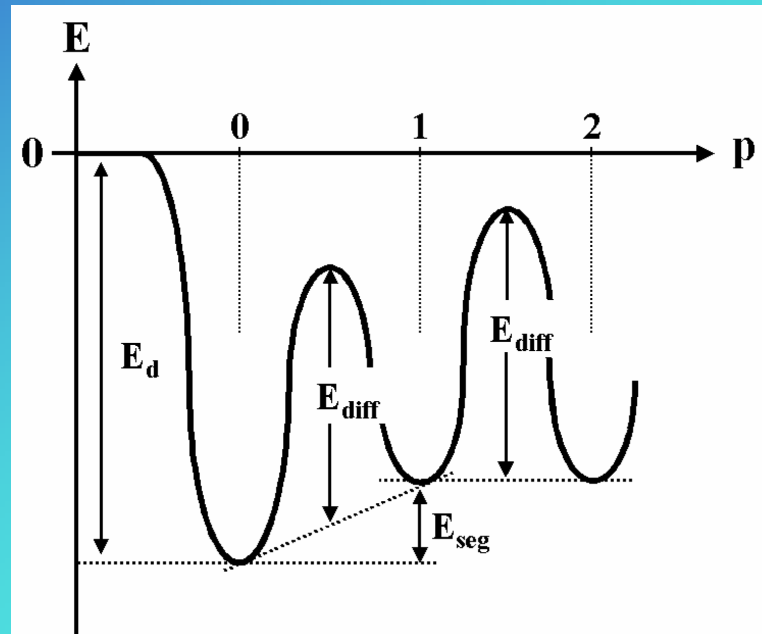
No effect of strain on r_{seg} at high temperature

Effect of x compensated by T_g





Segregation modelling



$$\frac{\partial C_0}{\partial t} = Z'\nu \exp\left(\frac{-E_{diff}}{kT}\right)\left[C_1(1-C_0)\exp\left(\frac{-E_{seg}}{2kT}\right) - C_0(1-C_1)\exp\left(\frac{+E_{seg}}{2kT}\right)\right] - J_{des}$$

At low T_G :

- **Effect of stress : related to kinetic diffusion**
- **Effect of chemistry : related to equilibrium segregation**

At higher T_G :

- **Equilibrium segregation**

Conclusion

Successful experimental procedure
Separation of strain / Ge content effects

Kinetic segregation → **Equilibrium segregation**

Fabrication of the structures at L.T. ⇨ kinetic segregation

- Suppression of segregation in relaxed layers
- Suppression of segregation in Ge rich layers