Patterned heteroepitaxial SiGe thin films through UV Excimer Laser radiation

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Outline

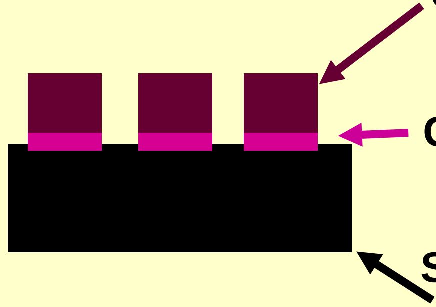
- **Aim of this study**
- **Some basics *(SiGe heterostructures & Laser processing)***
- **Obtained results:**
    - **Laser assisted growth through *LCVD***
    - **Laser induced epitaxy though *PLIE***
- **Conclusions**
- **Acknowledgements**

Aim of this study

Produce ultra-thin patterned

heteroepitaxial SiGe alloys on Si wafers

(Strained Ge rich layer buried under a Si rich cap layer)



Applications

Sacrificial layers for producing monocrystalline

- **Micro-(Nano)-Electro-Mechanical-System (MEMS, NEMS)**
- **Silicon-On-Nothing (SON) devices for IC technology**

Approach

Use laser assisted processes for producing

heteroepitaxial alloys with tailored concentration gradients on Si(100)

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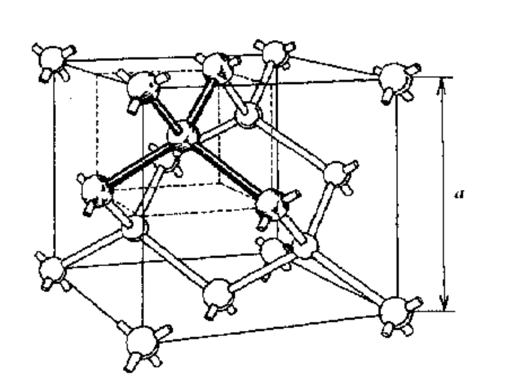
Laser assisted techniques:

- **Low thermal budget techniques that avoid heating up the complete substrate to > 500ºC**
- **Allow large area as well as local processing**
- **Reduce number of processing steps**
  (bottom-up instead of top-down)
- **Fast, relatively cheap *and* compatible with IC-processes**
- **Can be simulated (FEM) for reducing optimization costs**

Some basics (SiGe heterostructures & Laser processing)

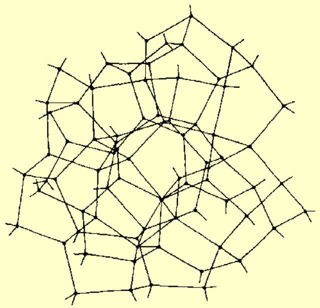
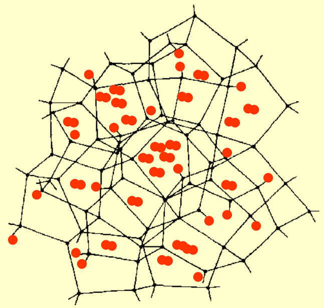
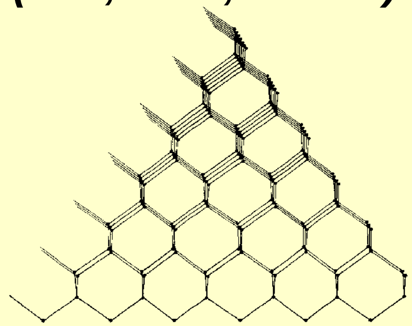
- **Based on group IV elements *(cubic cell)* with slightly different lattice constants**



E.Kasper (ed.) Silicon Germanium and SiGe:Carbon ISBN0852967837

a_{Si}: 0.5431 nm, a_{Ge}: 0.5657 nm

- **Different micro-structures are possible**

Amorphous (a-Si, a-Ge, a-SiGe)	*Hydrogenated amorphous (a-Si:H, a-Ge:H, a-SiGe:H)*	*Crystalline (c-Si, c-Ge, c-SiGe)*
		
(dangling bonds + voids)	*(saturated dangling bonds + stabilised voids)*	*(mono-, poly-, nano-)*

Composition and microstructure modifies optical & electrical properties, but also etching behaviour

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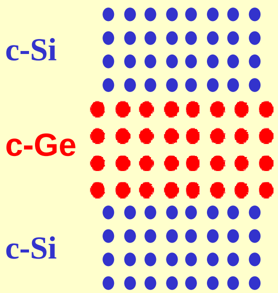
Problems related to crystalline SiGe heterostructures

➨ **Trying to match perfectly different lattice constants leads to tetragonal distortion**

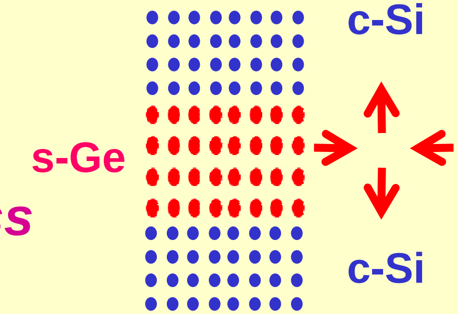


depending on film composition

Tensile / compressive strain

depending on film thickness

Defects and misfit dislocations



Tailoring concentration profile and thickness is essential for avoiding the formation and propagation of misfit dislocations

But: Hydrogen bonds might be helpful

➨ **Hydrogen can saturate dangling bonds in vacancies, defects, dislocations, and grain boundaries**

To produce c-SiGe using Hydrogen containing precursors should be beneficial and avoid post annealing processes with Hydrogen

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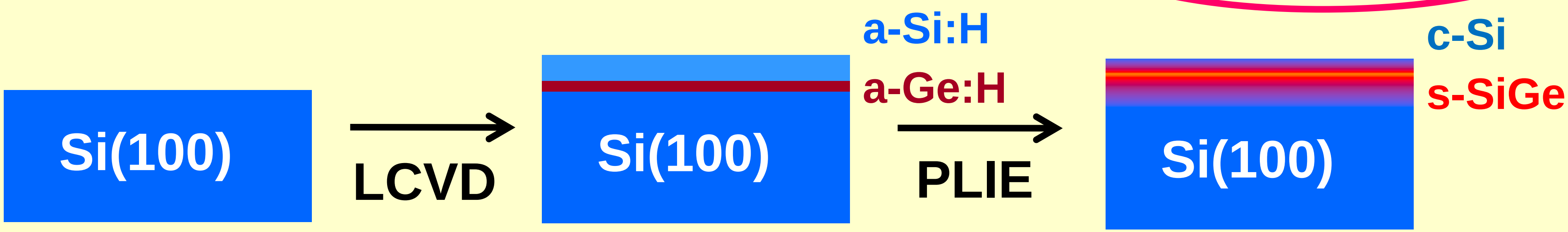
Some basics *(SiGe heterostructures & Laser processing)*

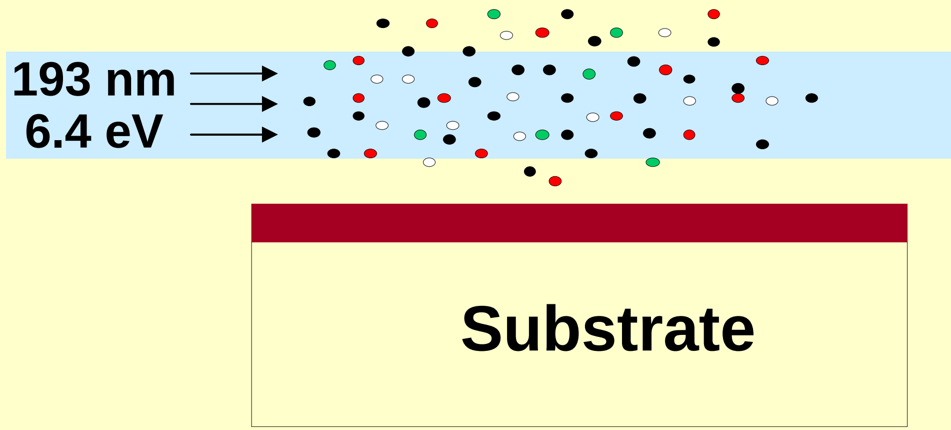


Laser Induced Chemical Vapour Deposition (LCVD)

(in parallel configuration)

1st step :

Photolysis of GeH_4 , Si_2H_6 in He



Following steps :

Chemical reactions in the gas phase and on the substrate surface lead to film formation at T_s > 120 ºC

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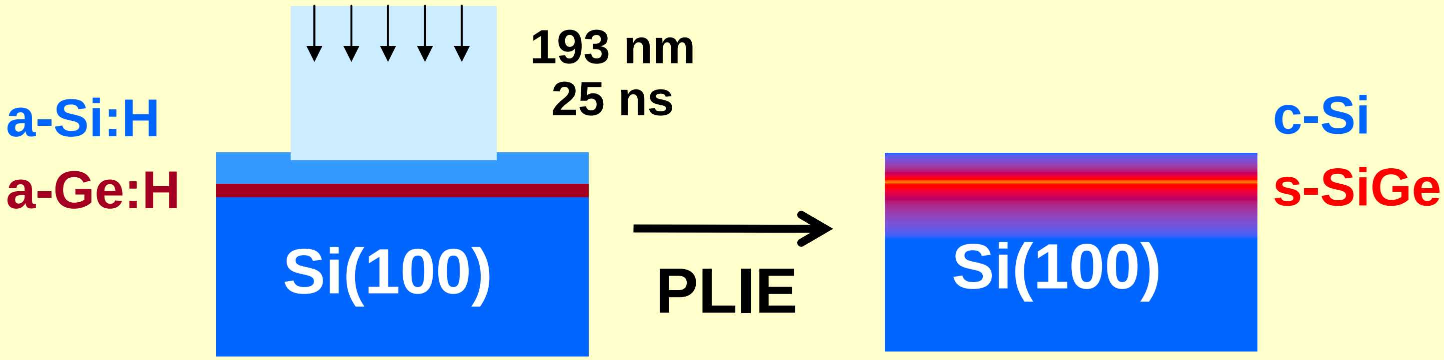
Pulsed Laser Induced Epitaxy (PLIE)

(in perpendicular configuration)

1. Absorption *(few nm in depth and in a well defined area)*
2. Fast local heating of a shallow near surface region *(within few ns)*



1.- Melting of the coating <u>and</u> the Si wafer surface

2.- Mixing of the elements in the molten pool *(tailoring of the [Ge] gradient)*

3.- Crystallisation using the substrate as seed *(heteroepitaxial growth)*

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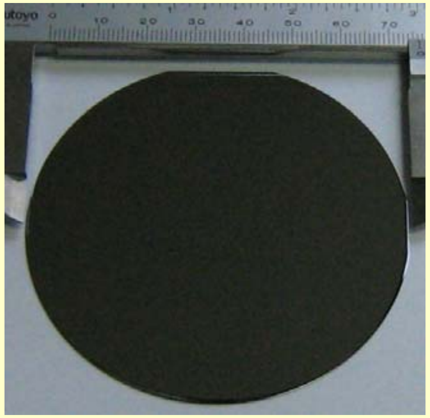
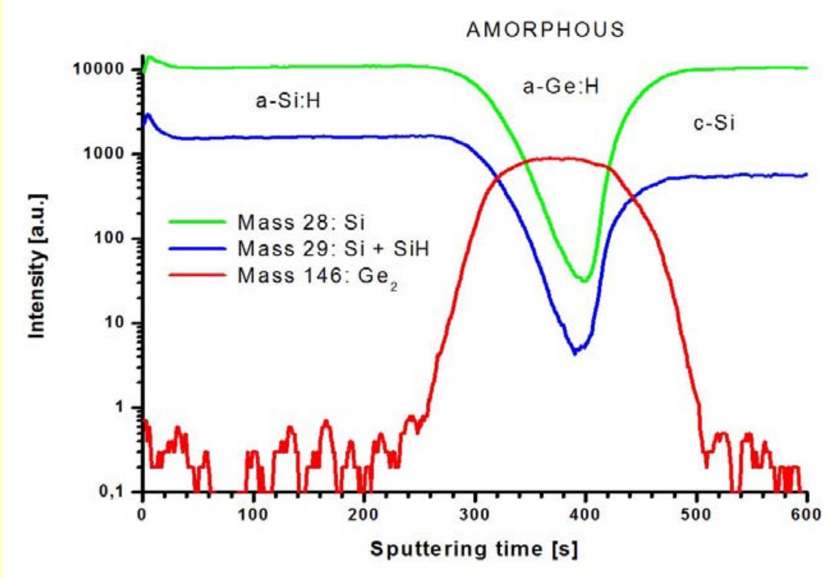
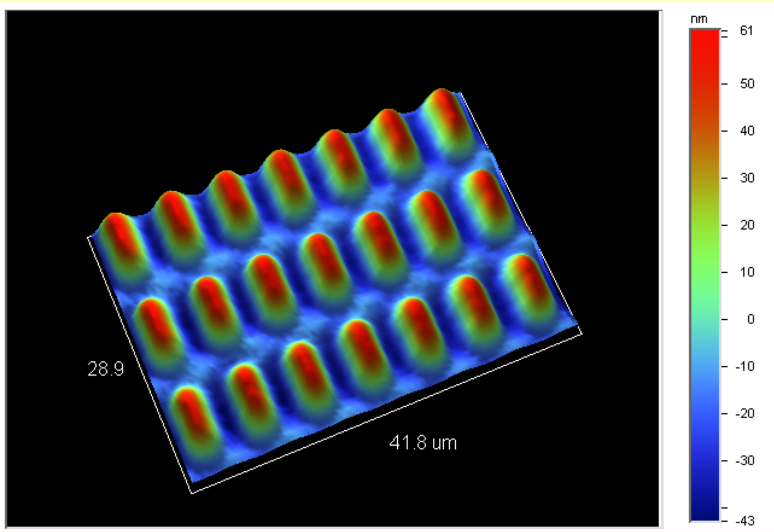
Obtained results: Laser assisted growth through *LCVD*

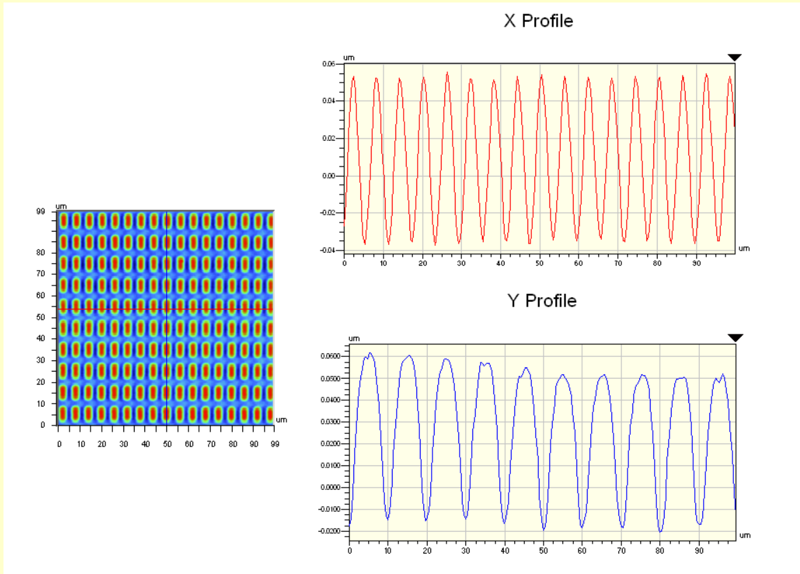
a-Si:H*(6nm)*/a-Ge:H*(3nm)* bi-layers
with uniform film thickness on Si(100) wafers





Patterned a-Si:H*(40nm)*/a-Ge:H*(20nm)* bi-layers (3 μm x 5 μm) using a shadow mask





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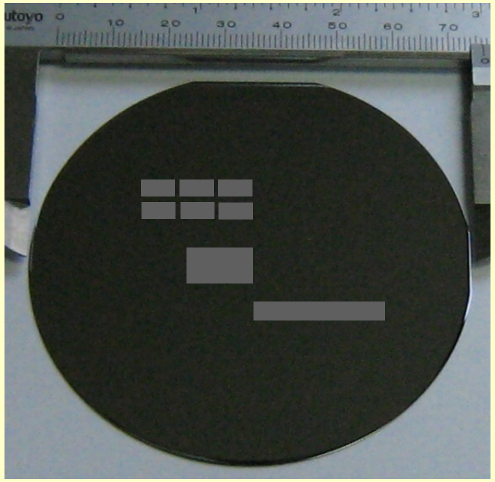
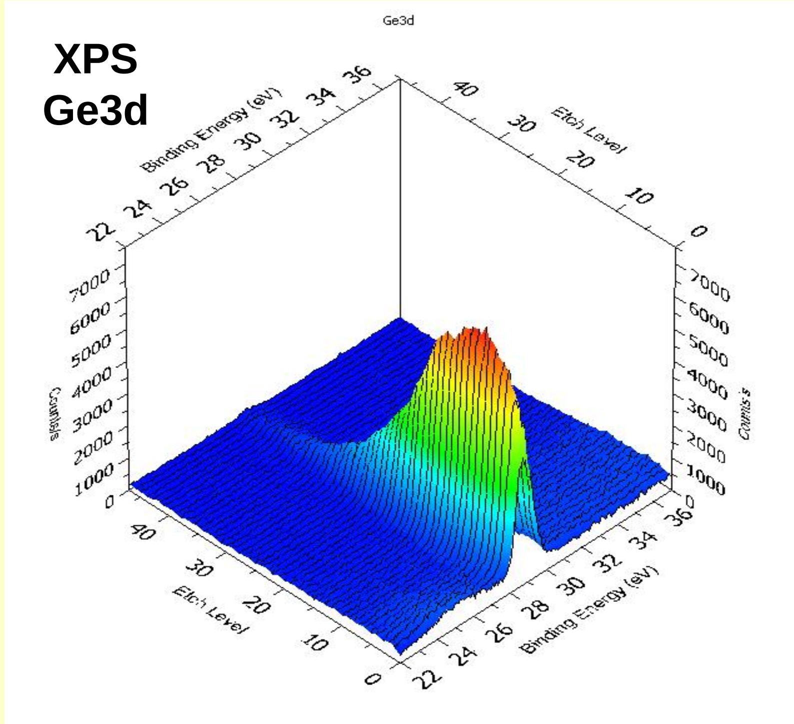
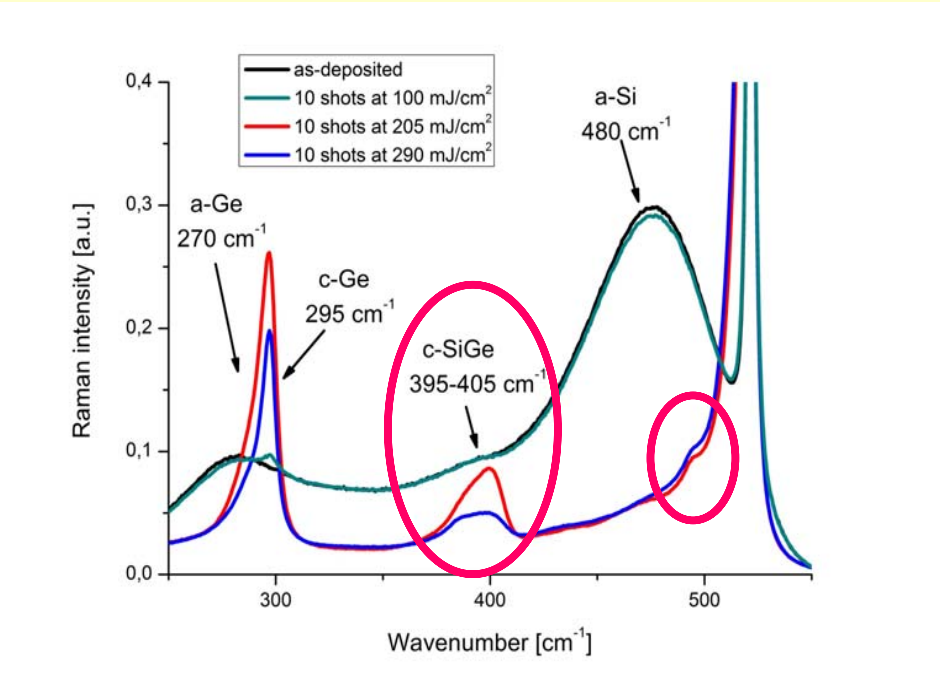
Obtained results: Laser assisted growth through *PLIE*



Formation of an heteroepitaxial alloy
(with a buried Ge rich layer in the inner part of a PLIE spot)



S.Chiussi et al. Applied Surface Science 254 (2008) 6030–6033



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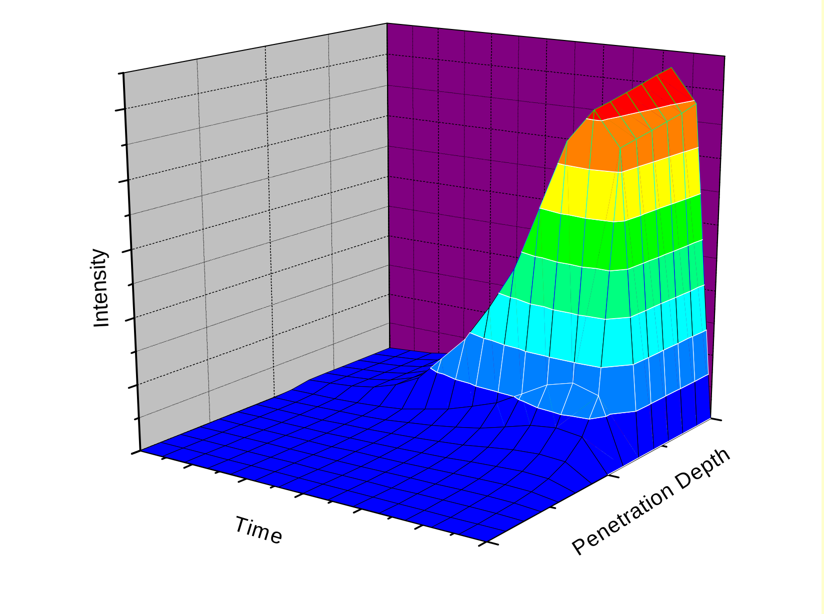
Numerical simulation of the Heat Conduction through Finite Element Method (FEM)

1. Calculate the decay of Laser intensity when penetrating into the material:

$$I(r,t) = I_o[1 - R(n,\kappa,\theta_o)]Exp(-\alpha y)$$



2. Consider:

- **initial surface Temperature of 25ºC**
- **heat is produced by the laser beam**

$$T(r,0) = T_o \qquad -k\frac{\partial T}{\partial z}\bigg|_{y(s)=0} = I(r,t)$$

3. Apply the Heat Conduction Differential Equation

to each consecutive cell of a grid simulating the structure

$$\rho(T)C(T)\frac{\partial T(\mathbf{r},t)}{\partial t} = \nabla[k(T)\nabla T(\mathbf{r},t)]$$

$T < T_{MP}$

$$\frac{\partial H(T)}{\partial t} = \nabla[k(T)\nabla T(\mathbf{r},t)]$$

$T > T_{MP}$

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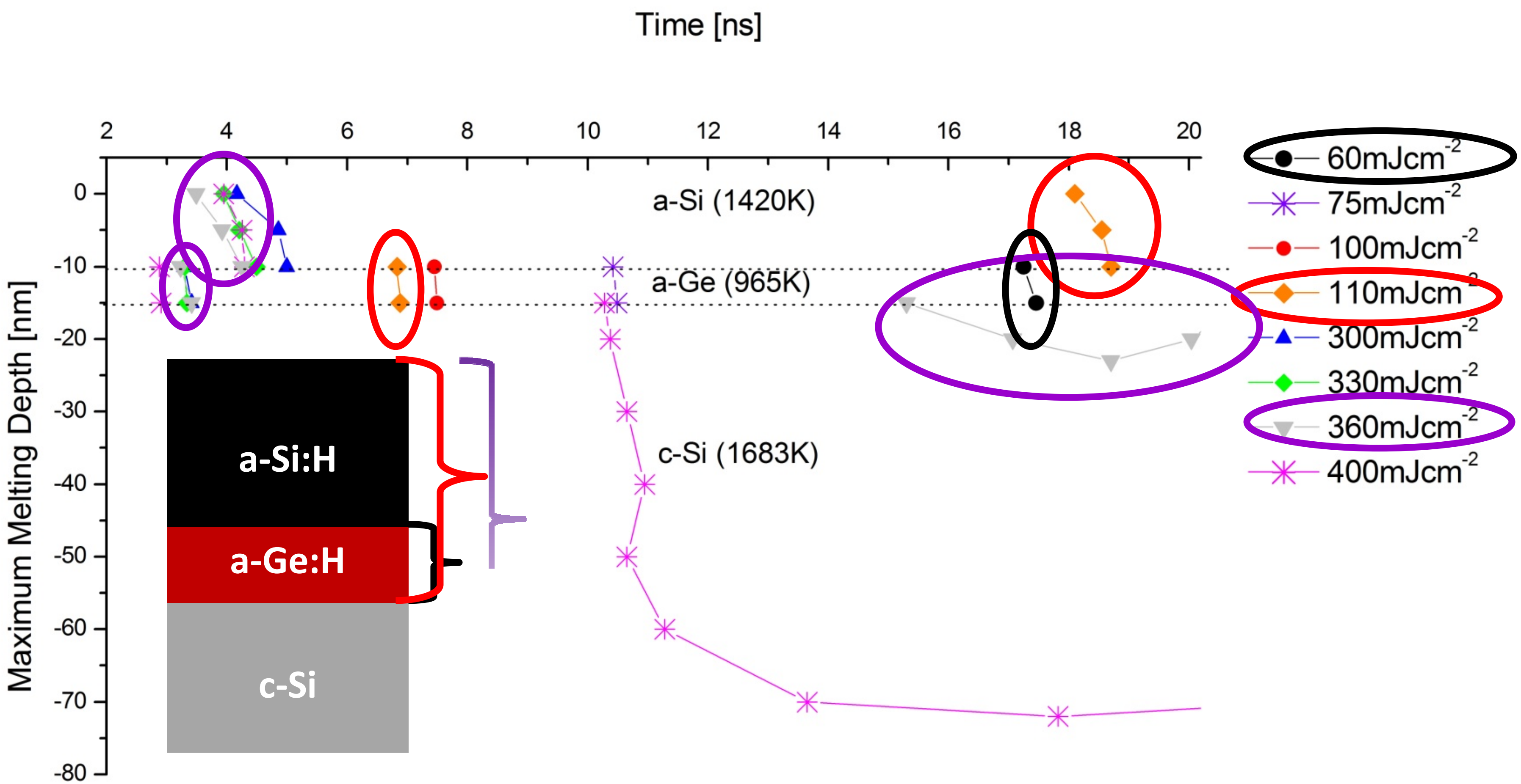
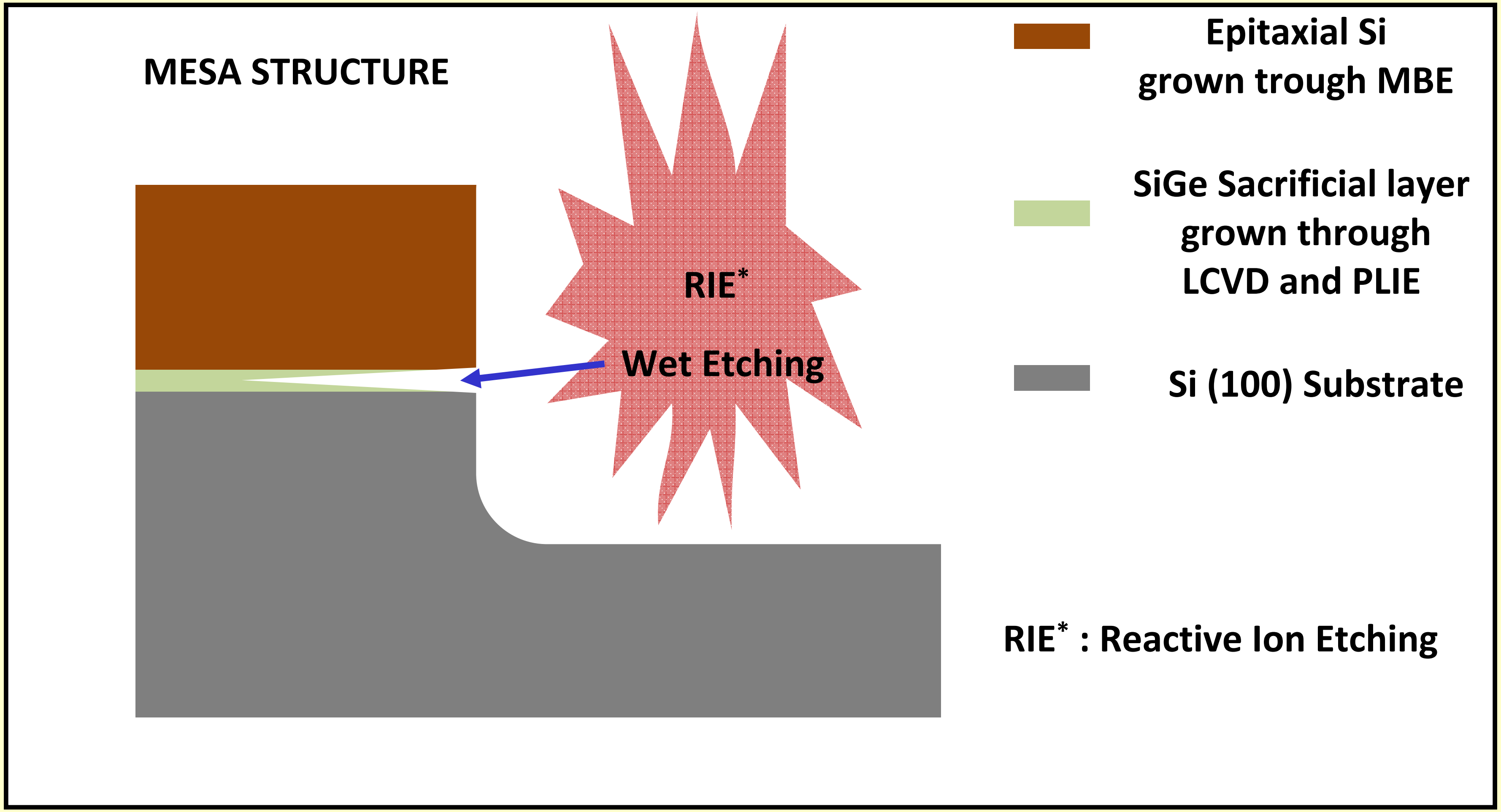


Whole bilayer melting achieved with 110 mJ/cm²

Substrate melting requires energy density above 350 mJ/cm²

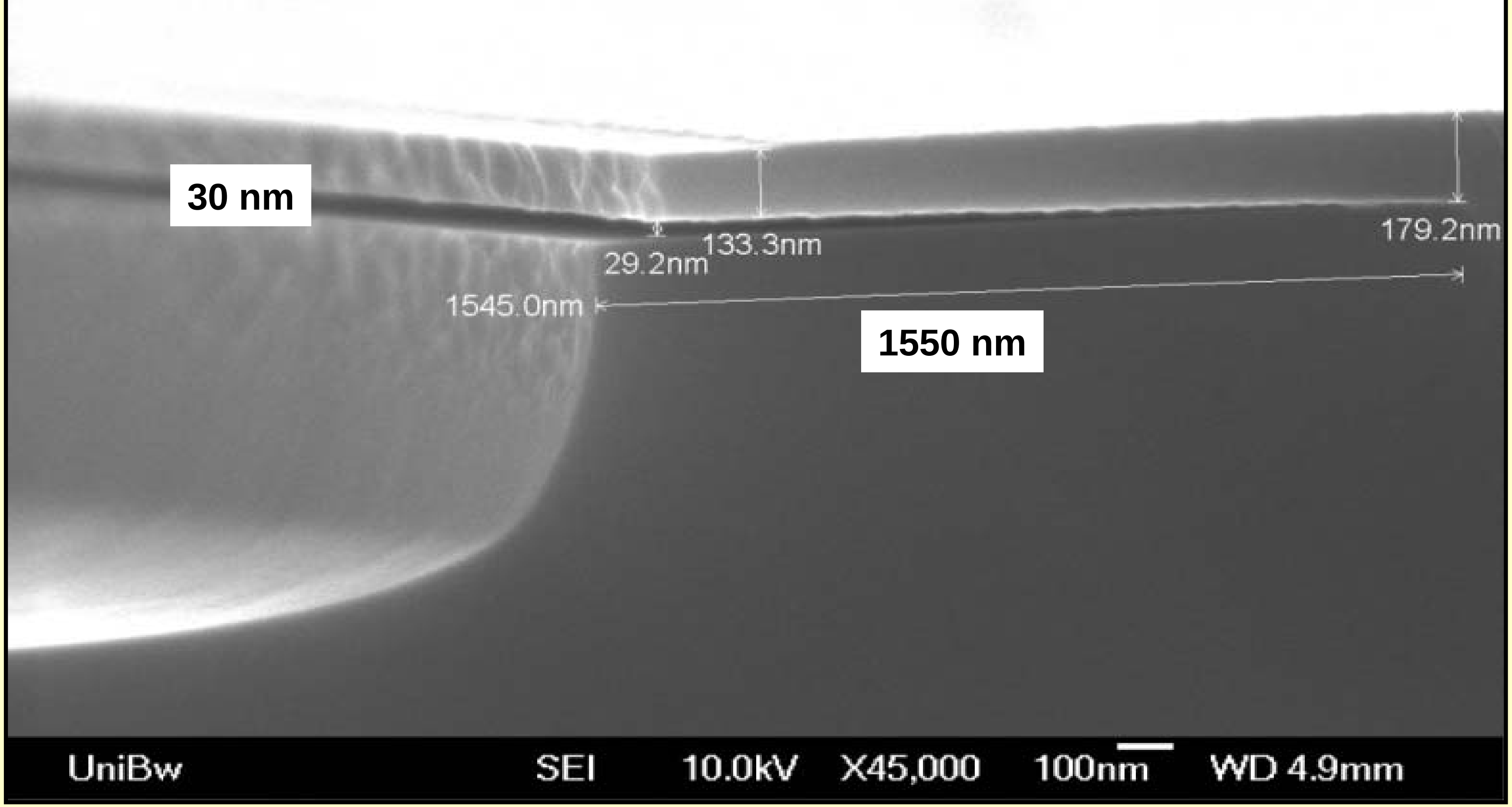
Compatibility with conventional IC's fabrication technology

MBE Si over-layer growth and etching of mesa structures with several lithography steps



Highly selective etching at RT

(indicating strong gradient and excellent epitaxy)



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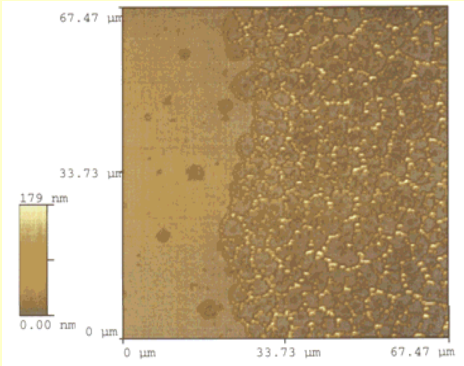
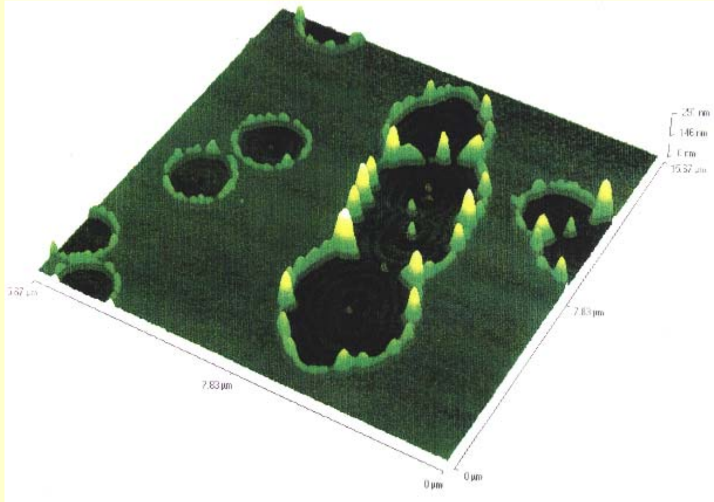
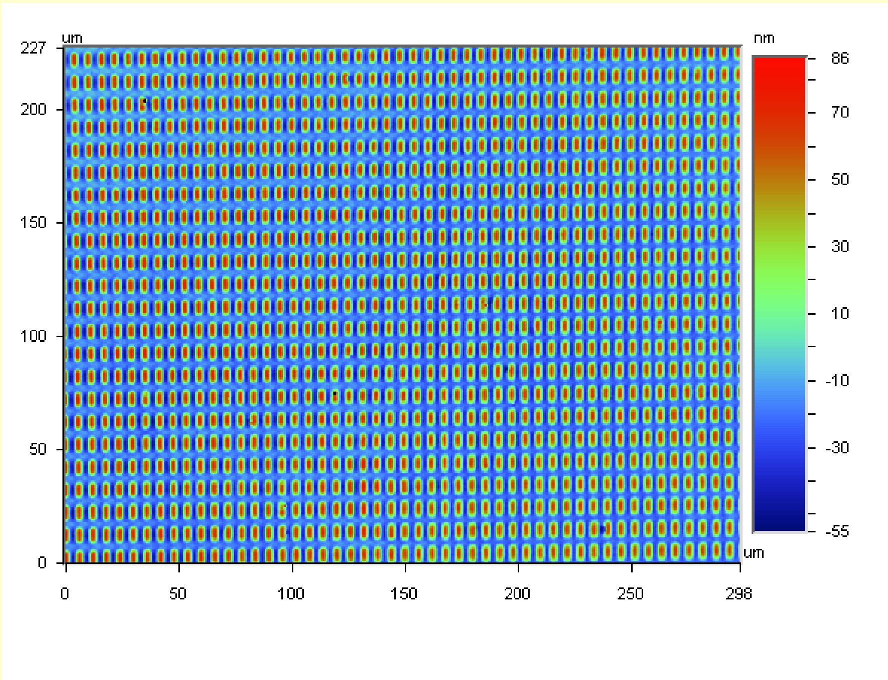
BUT

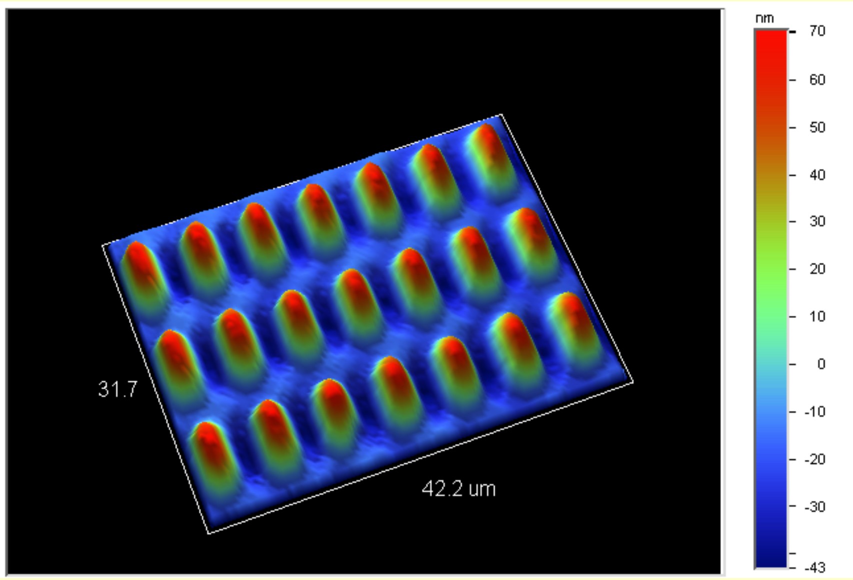
Borders of the spots are less well defined





Whereas patterns apparently maintain their structure after PLIE treatment with 10 pulses of 240 mJ/cm^2





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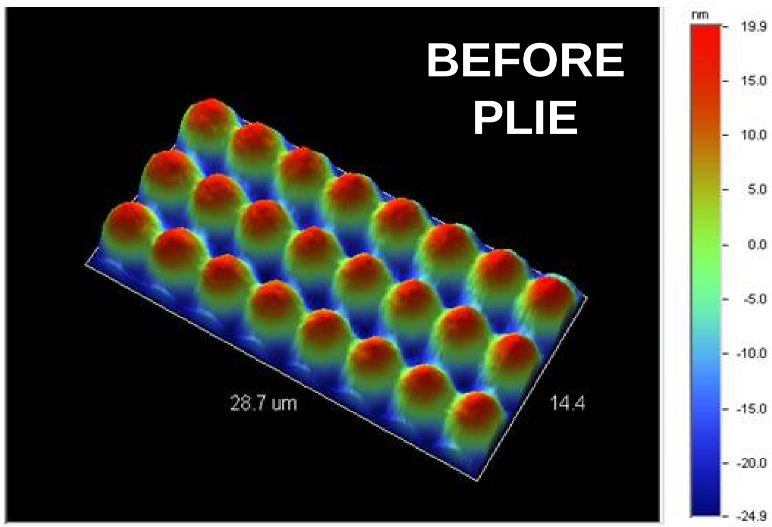
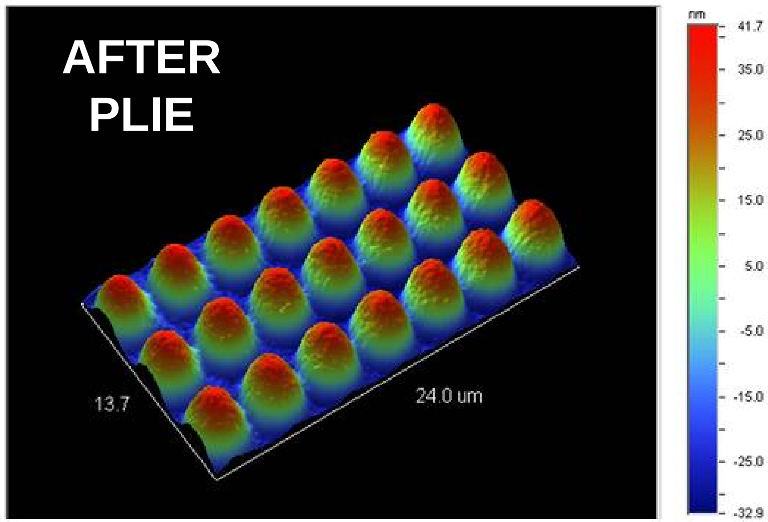
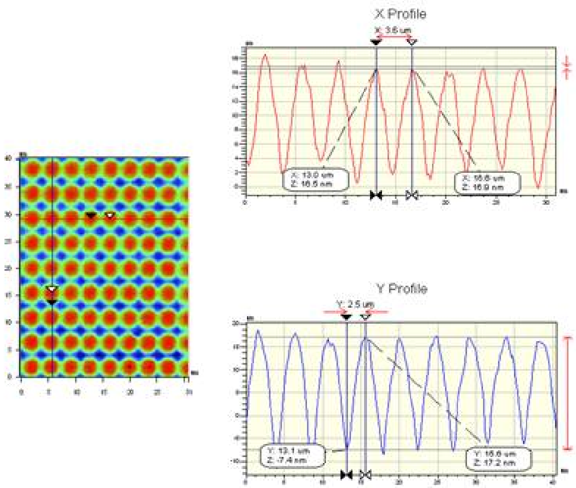
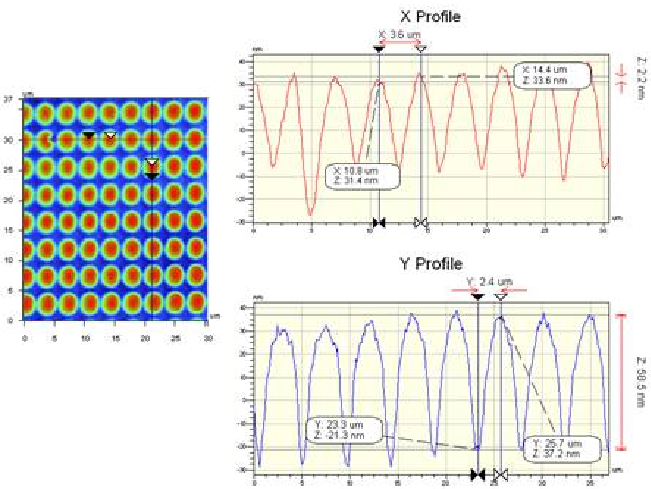
Enhancement of the microstructure aspect ratio







PLIE
240 mJ/cm^2



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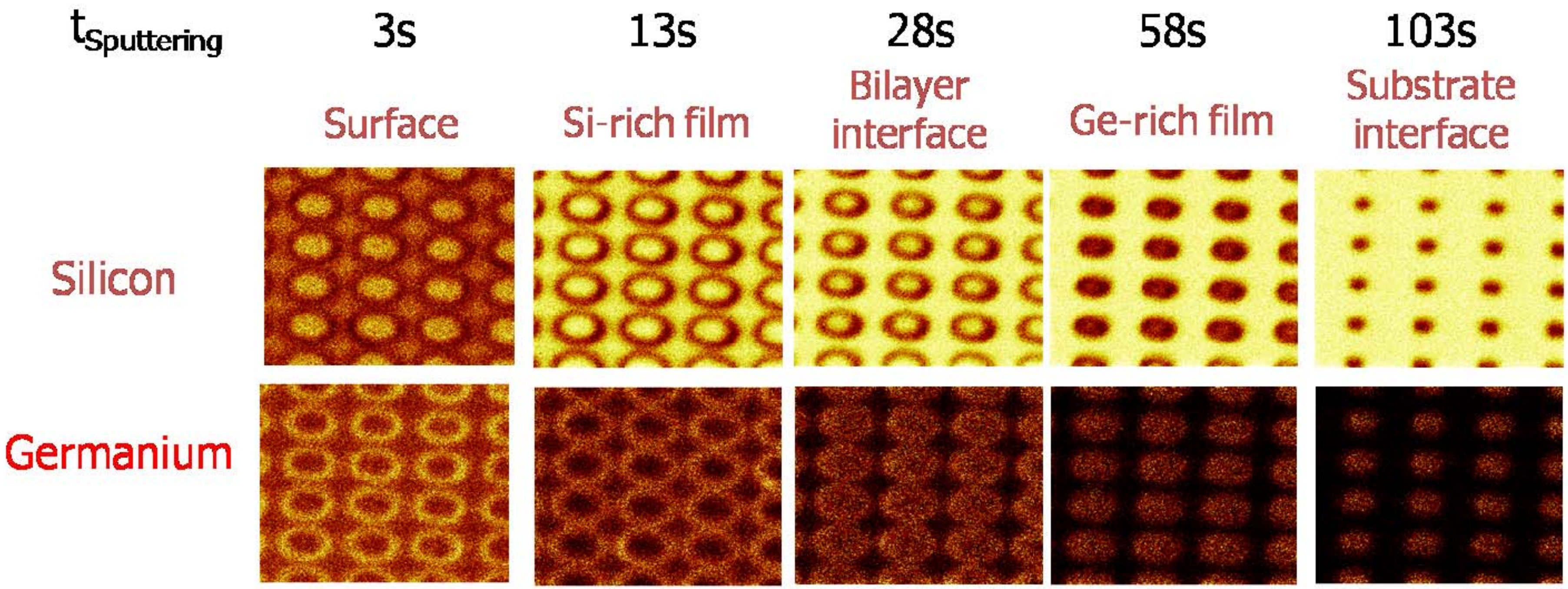
“Surprising” changes in composition

Features are now NOT perfectly uniform



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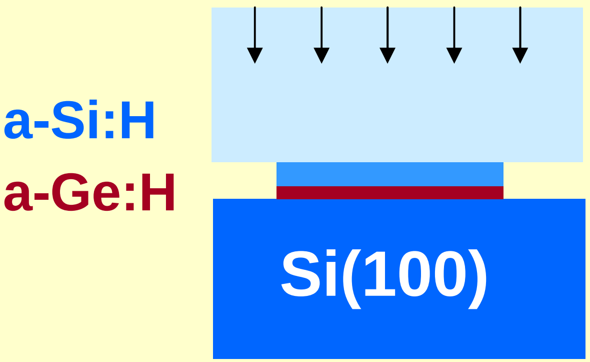
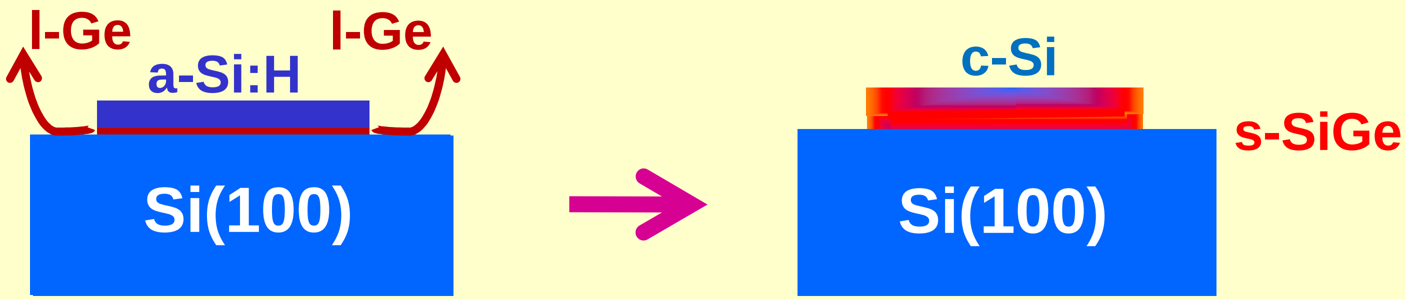


a-Ge:H melts earlier (965K) than a-Si:H (1410K) and solidifies later

Liquid Ge moves (segregates) during several tenth of ns, until solidification



Model has been confirmed by simulation (FEM), that include thermal stress calculations

Centre and edge have different melting thresholds producing thermal stress gradients, thus modification of Ge segregation

Changes in etching behaviour of the pattern !!!

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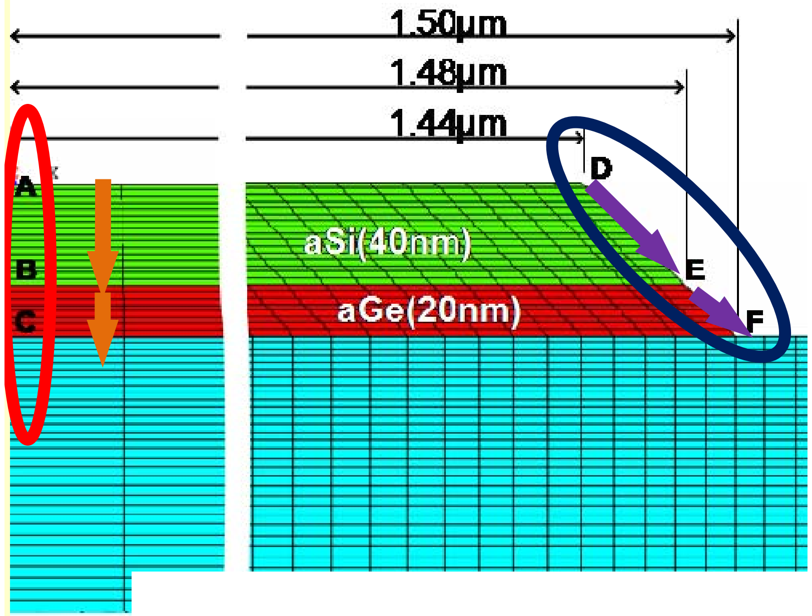
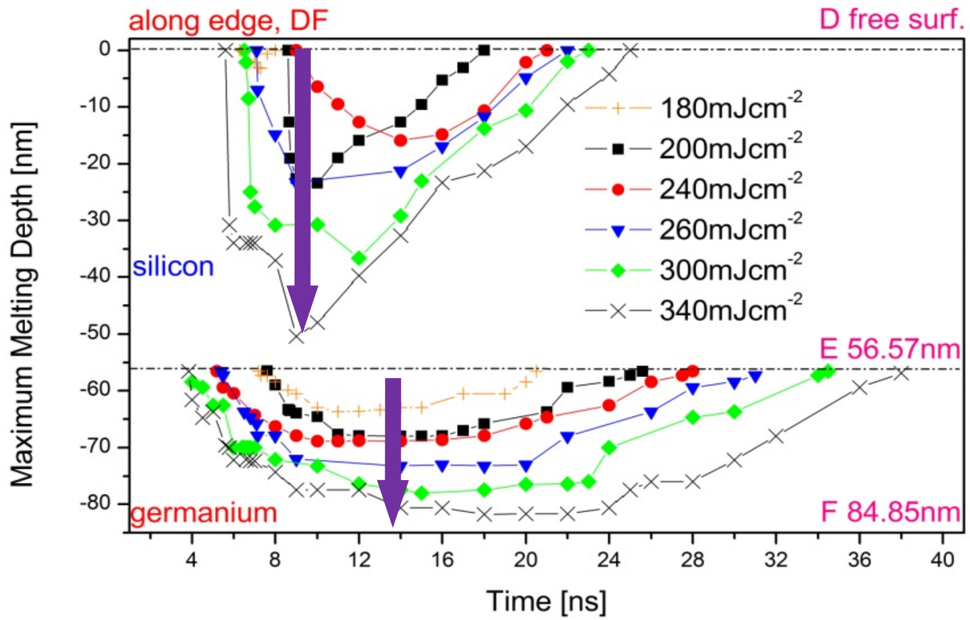
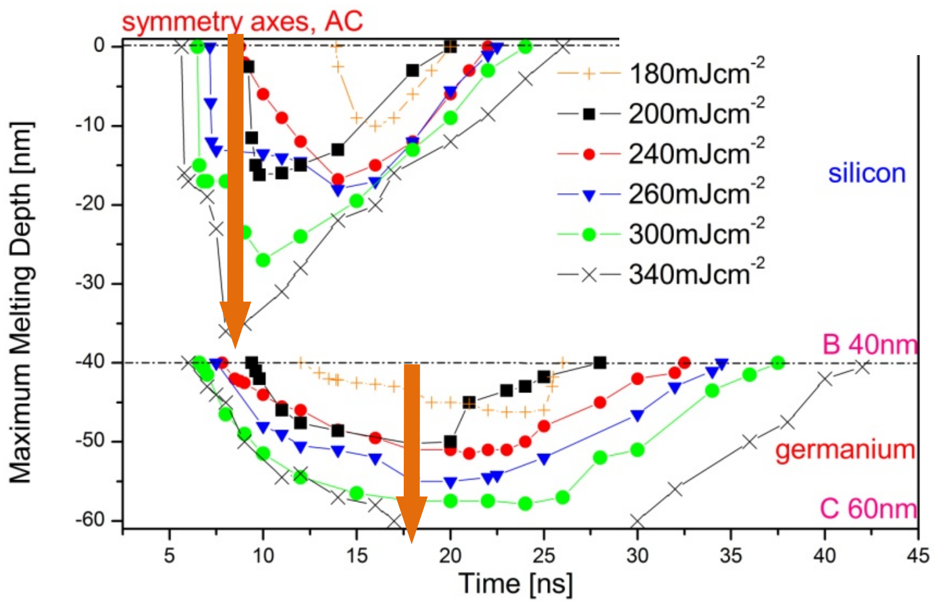






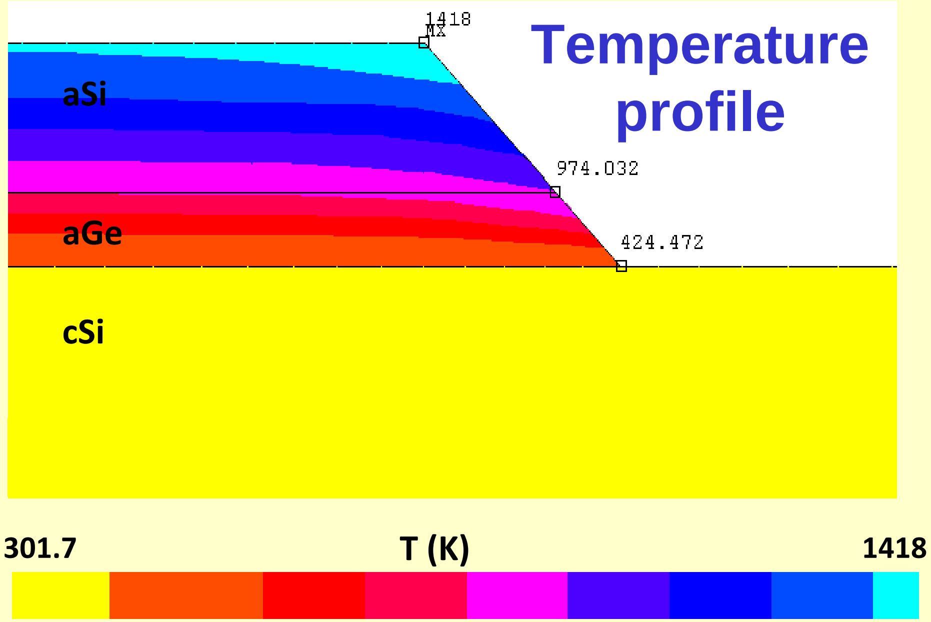
Melting threshold higher on the lateral edge

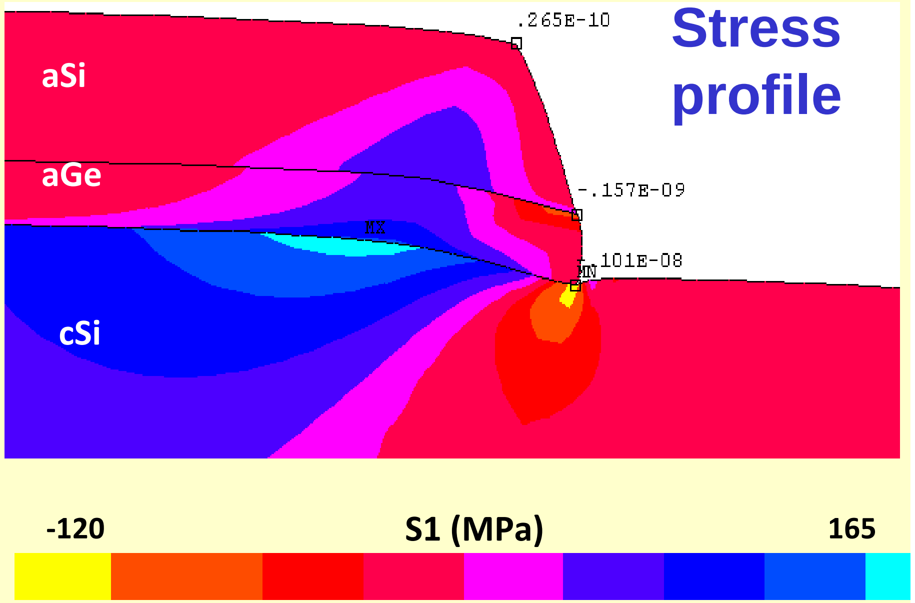
↓

Complex thermal gradients

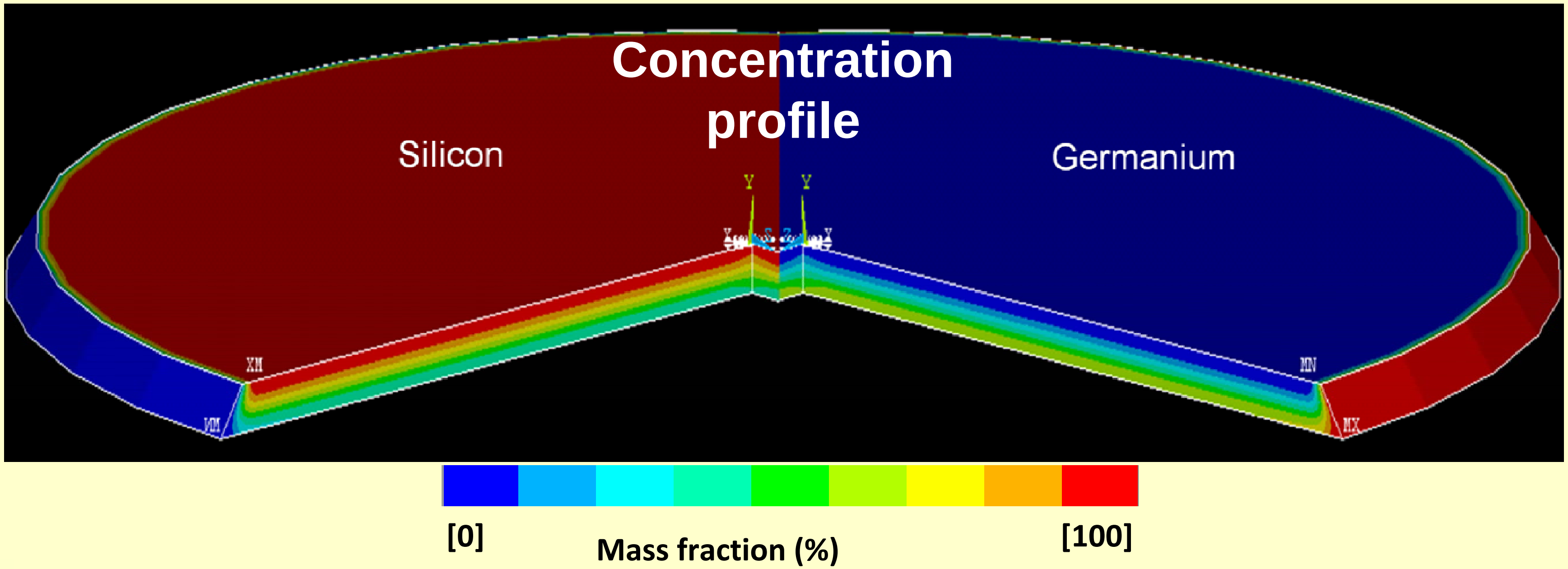
↓

Thermal stress





J.C.Conde et al. *Thin Solid Films 518 (2010) 2431–2436*



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Conclusions

LCVD on Si(100) wafers :

Uniform a-Si:H/a-Ge:H bi-layers can be produced,
both <u>locally</u> and in <u>large areas</u>

PLIE of LCVD grown bi-layers :

Heteroepitaxial structures with

- **s-Ge rich alloy buried under a Si rich layer**
- **Lateral Ge gradients when patterns are treated**
- **Numerical simulation of the PLIE process can predict Ge gradients both, vertical and lateral**

Samples have been successfully used as sacrificial layers in an IC process

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(IC processes)


Thank you for your attention !