FROM RESEARCH TO INDUSTRY

WET AND SICONI ®

CLEANING SEQUENCES FOR

SiGe EPITAXIAL REGROWTH

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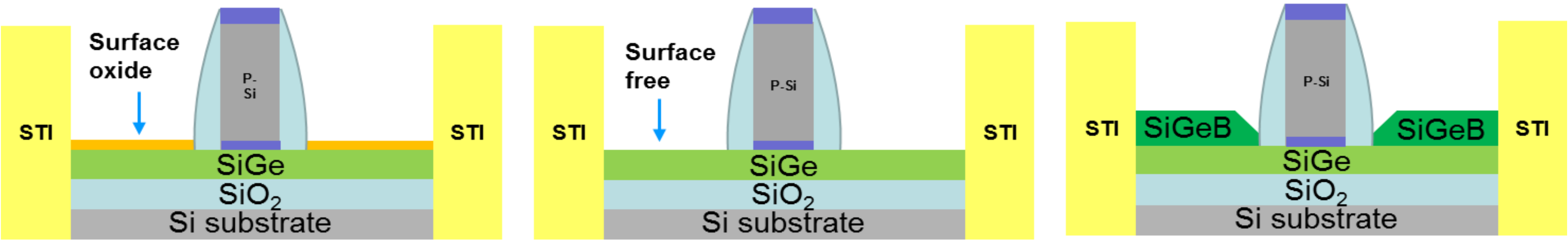
RAISED SOURCE/DRAIN EPITAXY FOR SUB 22 NM FD-SOI

FD-SOI architecture:

MOS bulk evolution:
- Low power consumption
- Good electrical performances

SOI substrate: Low thermal budget (Si Top layer)
SiGe channel: High air reactivity (re-oxidation)

Raised Source/Drain epitaxy



WET + H_2 Bake T°C <700°C

Epitaxial regrowth

Efficient and low thermal budget pre-epitaxial treatment mandatory to avoid dewetting especially for SiGe starting layers

WET surface preparation

- Diluted HF/HCl

DRY surface preparation

- Remote plasma (Siconi ®)

OUTLINE

WET Surface Preparation — **HF oxide and carbon removal efficiency**

DRY Surface Preparation — Siconi® oxide and carbon removal efficiency

WET and DRY Surface Preparation — Alternative WET and DRY combination for surface preparation

SiGe Epitaxial regrowth — Validate the efficiency of the alternative WET and DRY combination

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WET Surface Preparation	**HF oxide and carbon removal efficiency**
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SIGE 40% WET SURFACE PREPARATION

SiGe 40% grazing angle XPS quantification

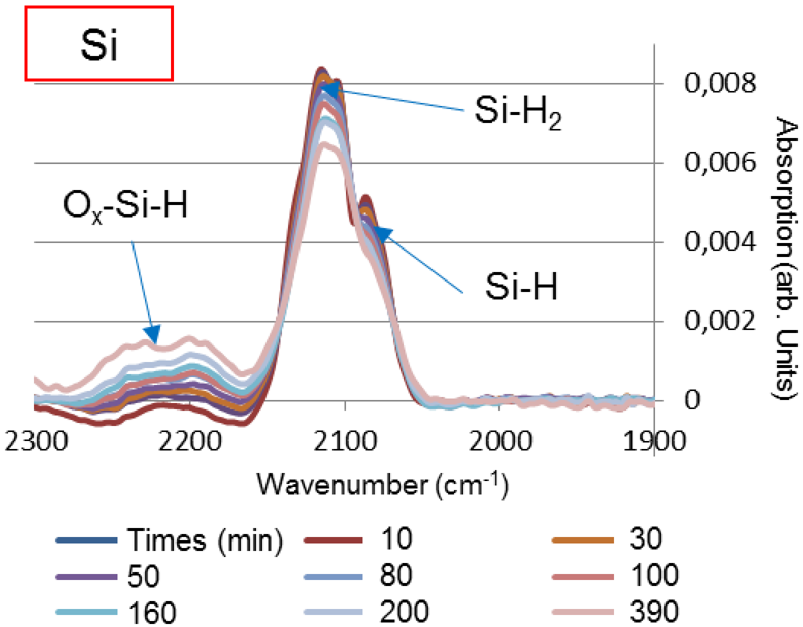
	Native oxide	WET clean
Air exposure		4 minutes
C % (C1s)	15,5	5
GeO_x % (Ge3d)	1,26	N.D.
GeO_2 % (Ge3d)	5,41	0
SiO_2 % (Si2p)	14,83	0

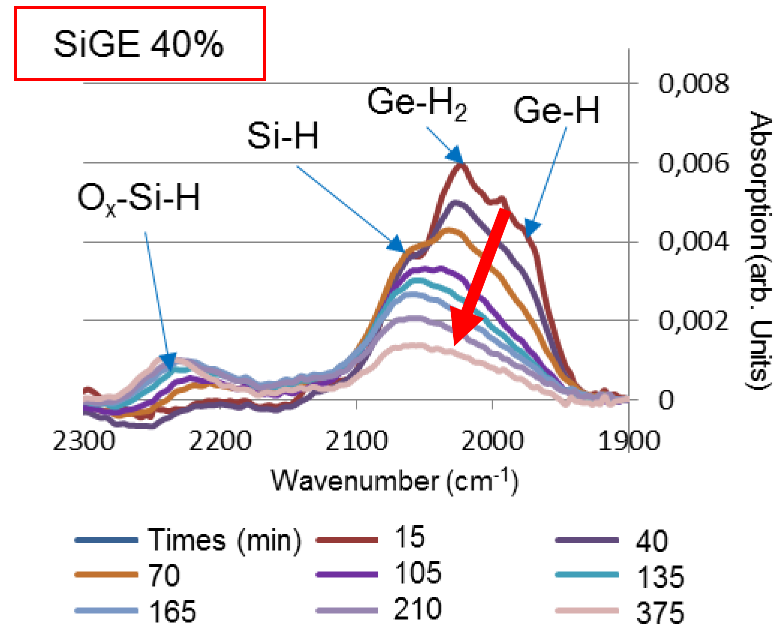
HF/HCl surface preparation of SiGe 40%:

- ➢ **efficient SiO_2, GeO_2 and Carbon removal**
- ➢ **Subject to air break**

SiGe 40% SURFACE REACTIVITY

Evolution of **IV-H bond** in atmosphere after HF clean (FTIR-MIR)





- IV-H bonds decrease after WET clean → formation of Si-O bonds
- Half of the Si-H and Ge-H loss after 2 hours for SiGe 40%

> - SiGe 40% Air break can not be managed
> - In-situ de-oxidation mandatory

AIR BREAK ISSUE

WET surface preparation:

Ex-situ WET CLEANING CHAMBER → **Epitaxial TOOL**

Air break unavoidable

DRY surface preparation:

In-situ DRY PLASMA CHAMBER → **Epitaxial TOOL**

No Air Break

DRY surface preparation useful for air sensitive material

- **Siconi®** → **remote plasma already used for SiO_2 removal and low thermal budget**

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SICONI PRINCIPLE

leti

1-Etchant Generation (remote plasma)

$NF_3 + NH_3 \xrightarrow{RF} NH_4F + NH_4F.\ HF$

2-Etch Process

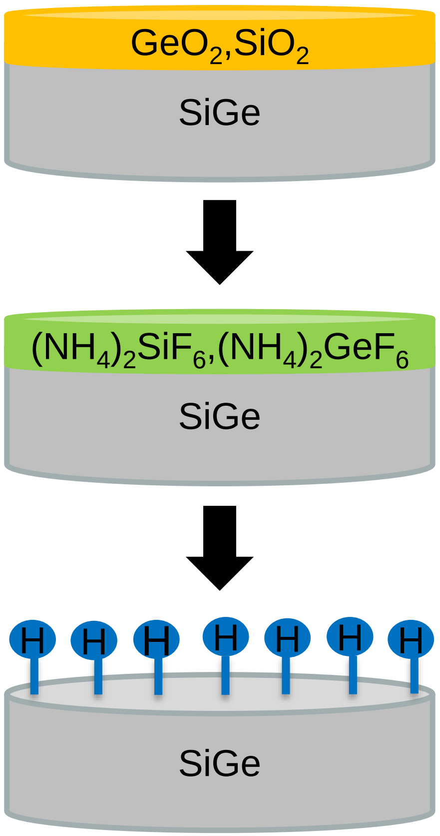
$SiO_2 + 4\ HF + 2\ NH_4F \rightarrow (NH_4)_2SiF_6$ (solid) $+ H_2O$

$GeO_2 + 4\ HF + 2\ NH_4F \rightarrow (NH_4)_2GeF_6$ (solid) $+ H_2O$

3- Anneal Process (>100 °C)

$(NH_4)_2\ SiF_6$ (solid) $\rightarrow SiF_4(g) + NH_3\ (g) + HF(g)$

$(NH_4)_2\ GeF_6$ (solid) $\rightarrow GeF_4(g) + NH_3\ (g) + HF(g)$



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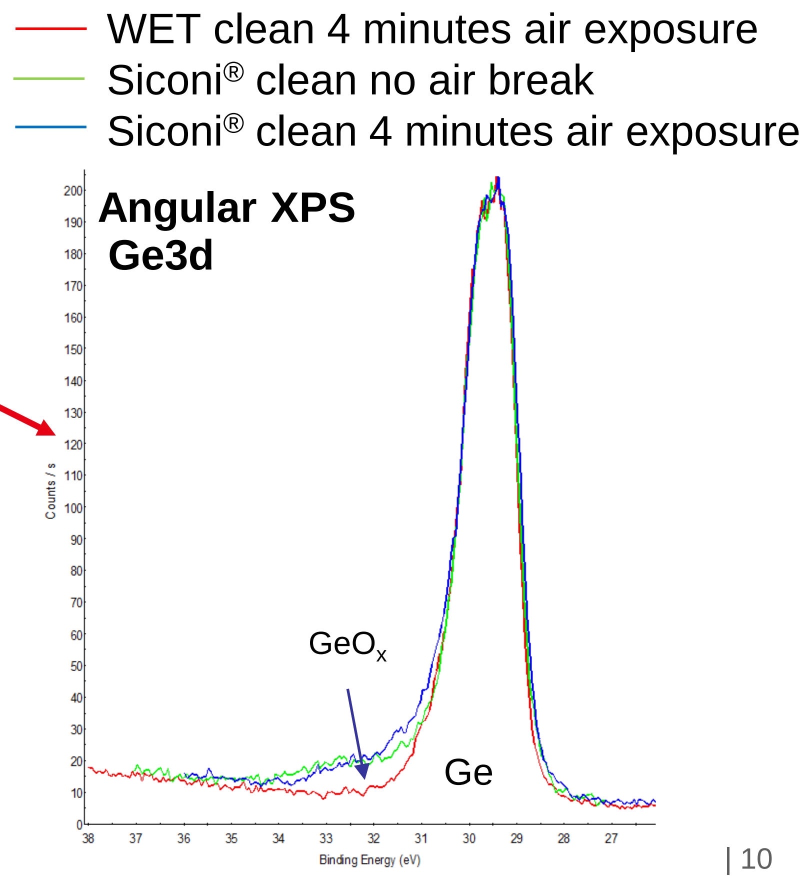
IN-SITU SICONI® SURFACE PREPARATION OF SiGe 40%

Efficiency of Siconi® and HF-Last on GeOx removal

SiGe 40% grazing angle XPS quantification

	Native oxide	Siconi®
Air exposure		4 minutes
GeO_2 % (Ge3d)	5,41	0
SiO_2 % (Si2p)	14,83	0
GeO_x % (Ge3d)	1,26	< LLD
C % (C1s)	15,5	12,6



Siconi® :

- ➢ **Efficient SiO_2 et GeO_2 removal**
- ➢ **Less efficient on Carbon and GeO_x**

SUMMARY

WET Surface Preparation

HF oxide and carbon removal efficiency

DRY Surface Preparation

Siconi® oxide and carbon removal efficiency

WET and DRY Surface Preparation

Alternative WET and DRY combination for surface preparation

SiGe Epitaxial regrowth

Validate the efficiency of the alternative WET and DRY combination

ALTERNATIVE STRATEGY FOR SiGe 40% SURFACE PREPARATION

GeO_2 GeO_x SiO_2 C

SiGe 40%

Si

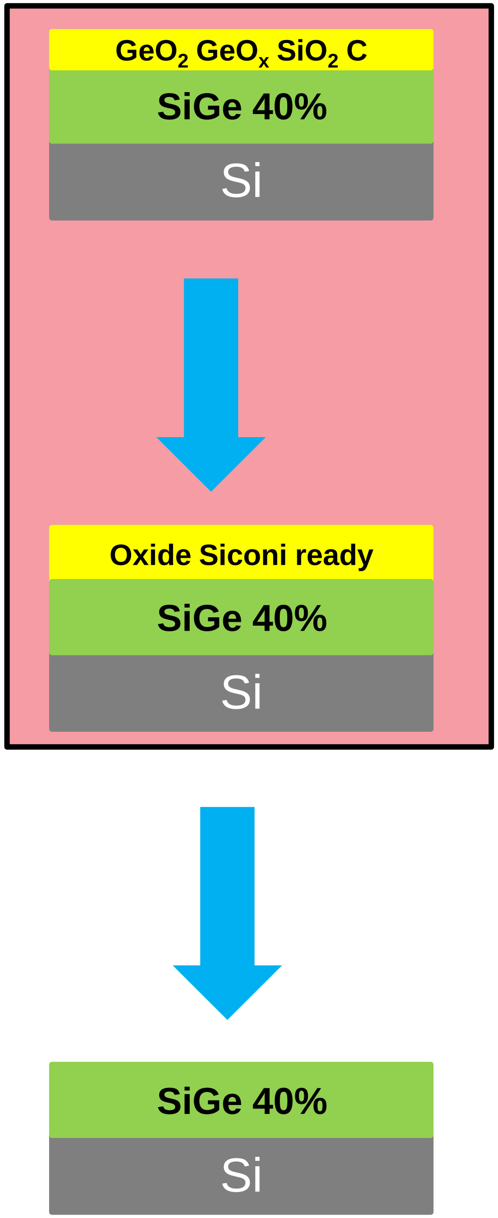
Native oxide

SiGe 40%

Si

Goal : Epi ready surface (without Oxygen, Carbon…)

ALTERNATIVE STRATEGY FOR SiGe 40% SURFACE PREPARATION



Native oxide

Can an oxidant solution:

- Change the oxide chemical composition?
- Remove the Carbon contamination?

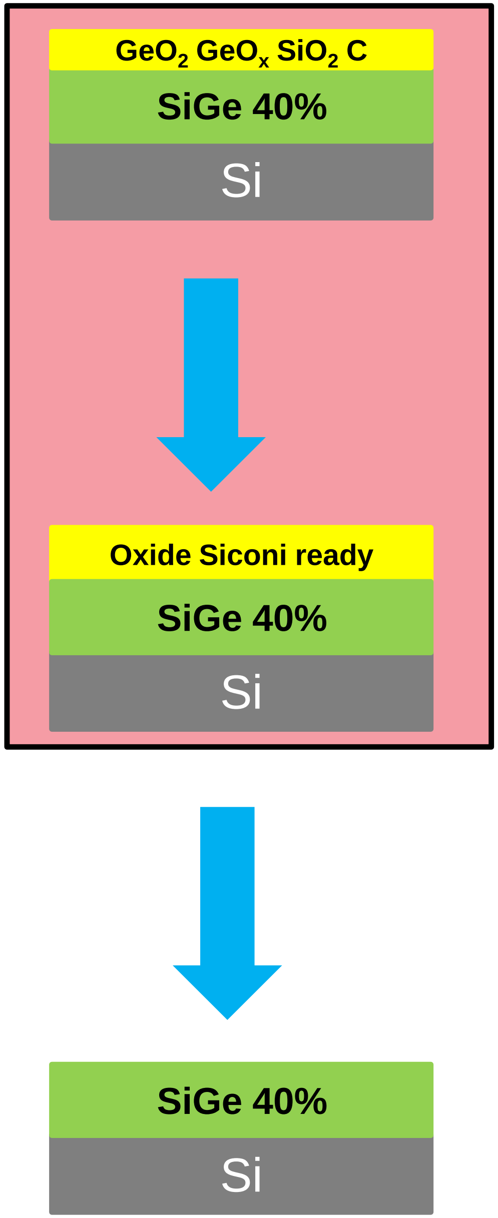
Siconi ® less efficient on:

- GeO_2, GeO_x and Carbon

No air break → Siconi®

Goal : Epi ready surface (without Oxygen, Carbon…)

ALTERNATIVE STRATEGY FOR SiGe 40% SURFACE PREPARATION



Native oxide

SiGe 40% chemical oxide

	Native oxide	HF-Ozone	HF-COLD SC1
SiO_2% (Si2p)	14,83	18,5	18
GeO_2% (Ge3d)	6,7	1,8	N.D.
C% (C1s)	15,5	3,5	N.D.

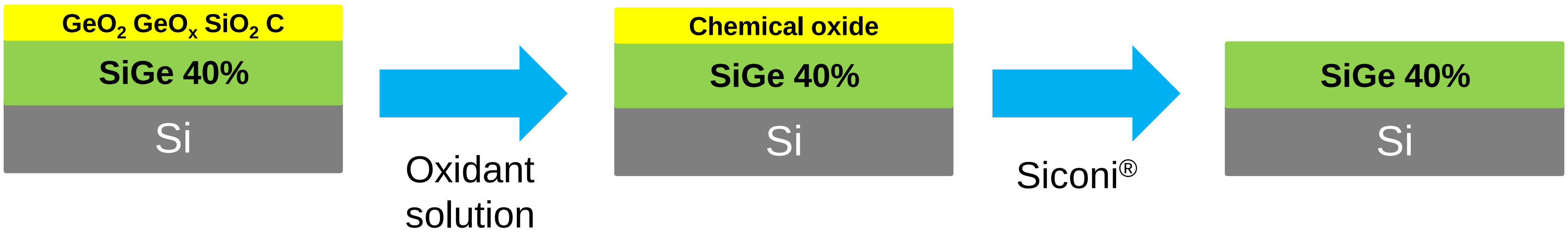
- Chemical oxide mostly SiO_2
- No carbon contamination

Does chemical oxide presence induce an efficient oxygen and carbon removal with Siconi?

No air break → siconi®

Goal : Epi ready surface (without Oxygen, Carbon…)

SiGe 40%SURFACE STATE AFTER VARIOUS PREPARATIONS



Angular XPS Quantification SiGe 40%

	Siconi	HF	HF-Siconi®	HF-COLD SC1-Siconi®	HF-HOT SC1-Siconi®	HF-Ozone-Siconi®
O % (O1s)	10.41	8,54	6.78	N.D.	N.D.	N.D.
C % (C1s)	10.87	3.26	4.23	N.D.	N.D.	N.D.

Efficiency on Oxygen and Carbon removal

HF-Chemical oxide-Siconi® → Lowest Oxygen and Carbon contamination

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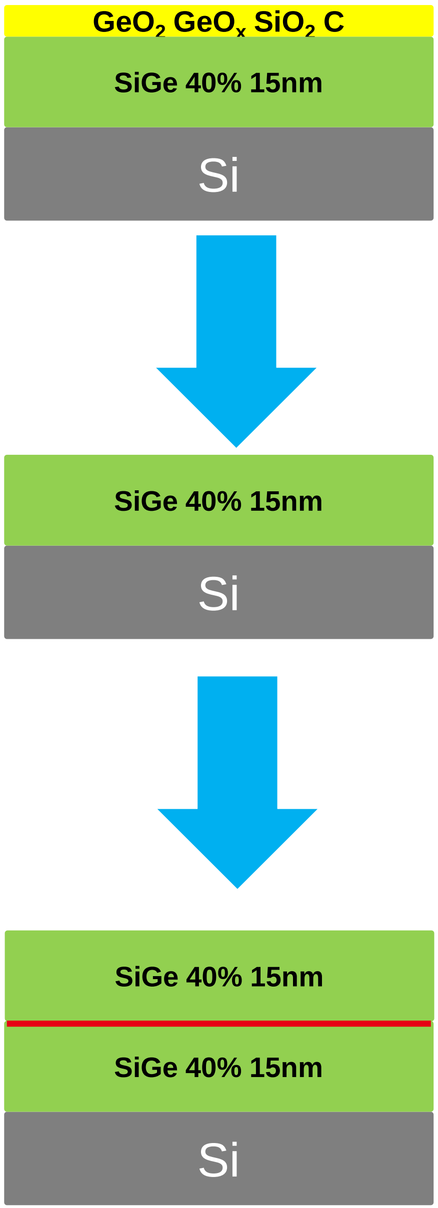
STUDY OF EPITAXIAL REGROWTH

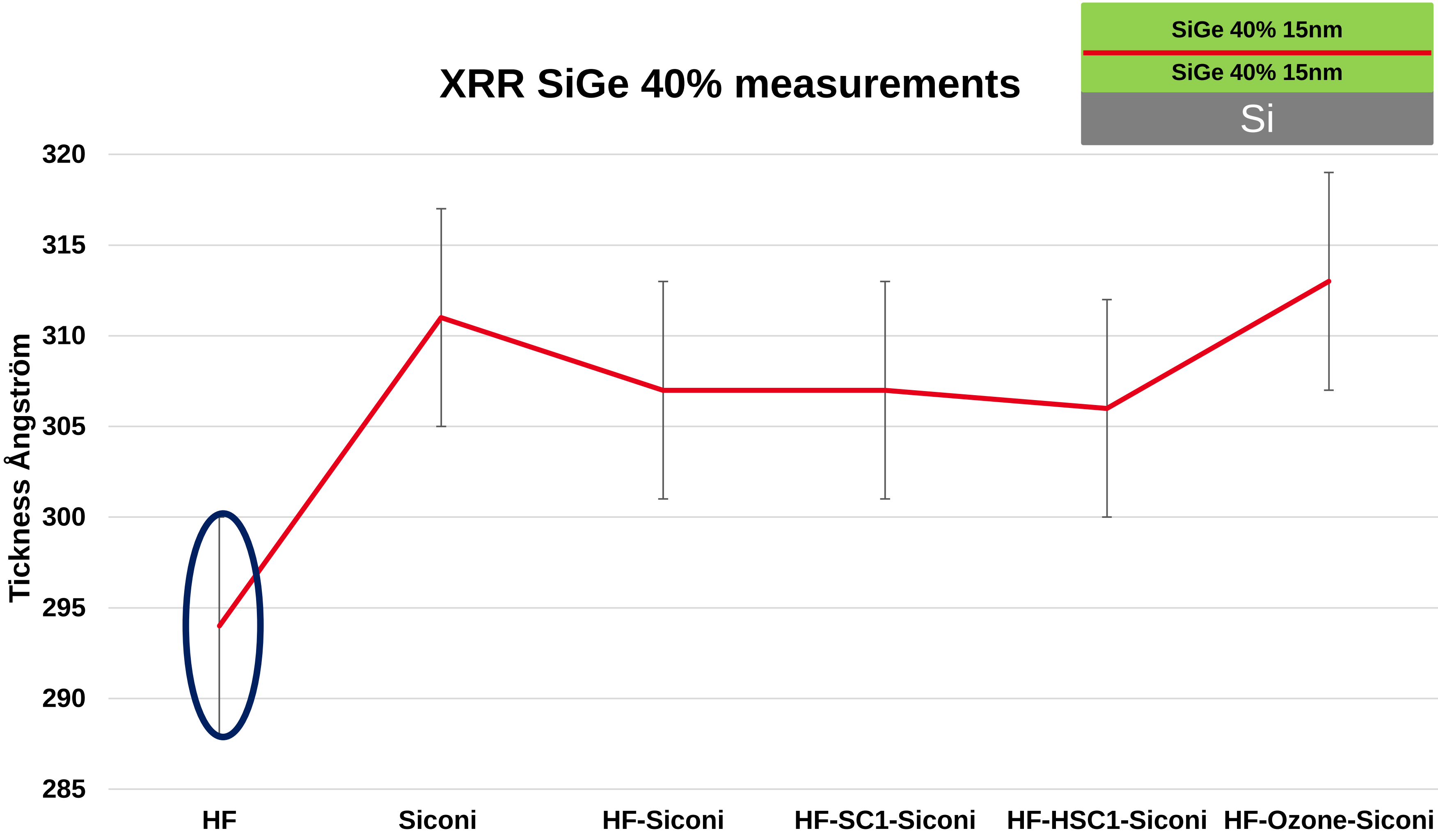


Various surface preparations for remove the oxide

Low temperature H_2 Bake and SiGe 40% epitaxial regrowth

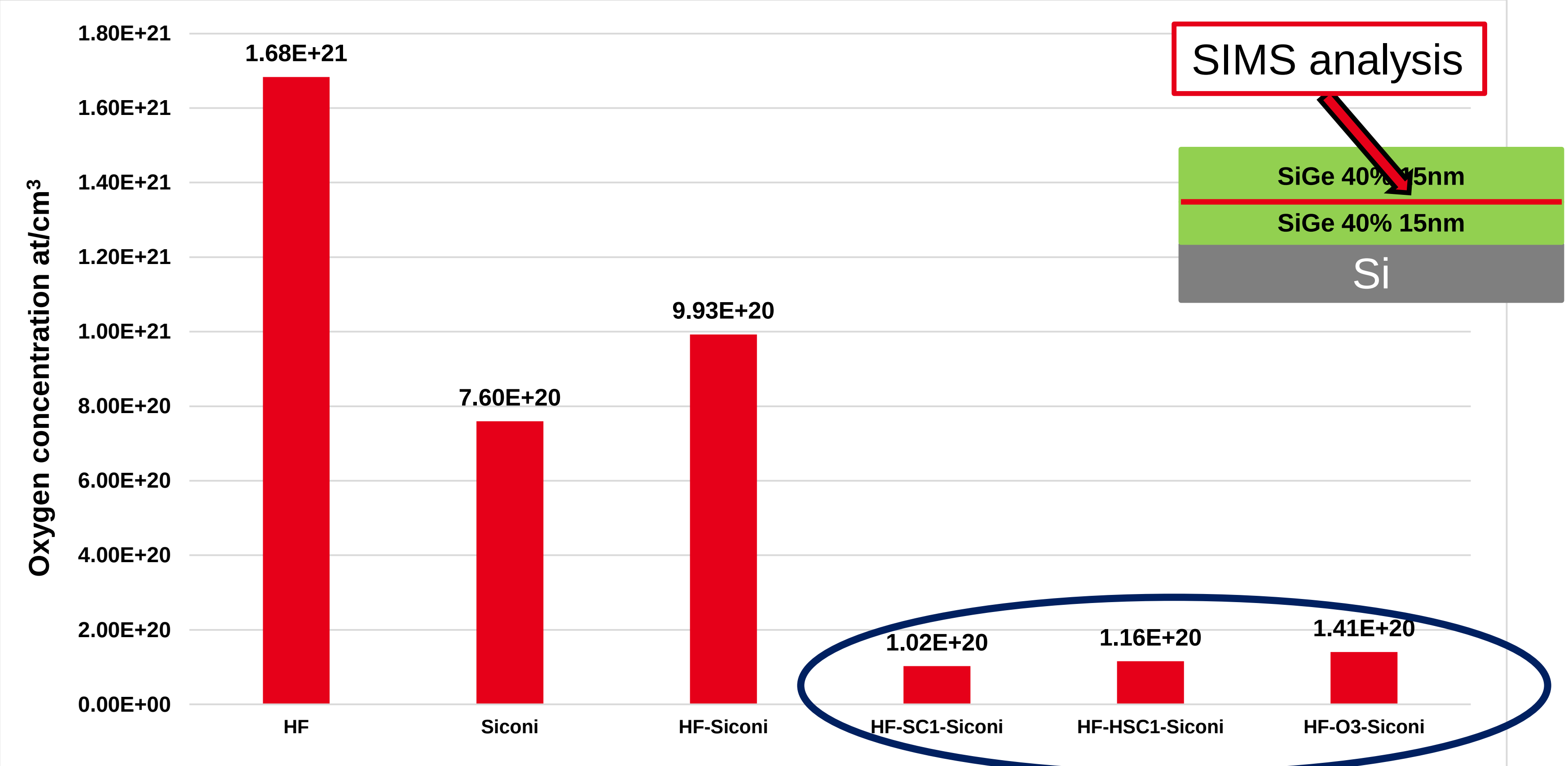
Thickness of the layer with XRR
SIMS analysis of the interfacial contamination

SIGE 40% EPITAXIAL THICKNESS



Growth delay with HF-Last surface preparation
Suggest high Oxygen interfacial contamination

OXYGEN INTERFACIAL CONTAMINATION (SIMS ANALYSIS)



- HF-last: highest Oxygen concentration

- HF-Chemical Oxide-Siconi® yields the lowest oxygen concentration
- SIMS in line with XPS results

- No Carbon contamination detected for the various treatments
- Siconi® only: efficient removal of the C contamination by the H_2 bake

CONCLUSIONS

ex-situ HF-last :

- Surface sensitive to re-oxidation
- HF treatment suffers from regrowth delay
- highest Oxygen interfacial contamination

“In-situ” Siconi®:

- No regrowth delay
- Oxide interfacial contamination still present

HF-Chemical oxide-Siconi®:

- No regrowth delay
- Lowest Oxygen interfacial contamination
- The chemical oxide generated yields an efficient removal of the oxide with the Siconi process

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J.M. Hartmann

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