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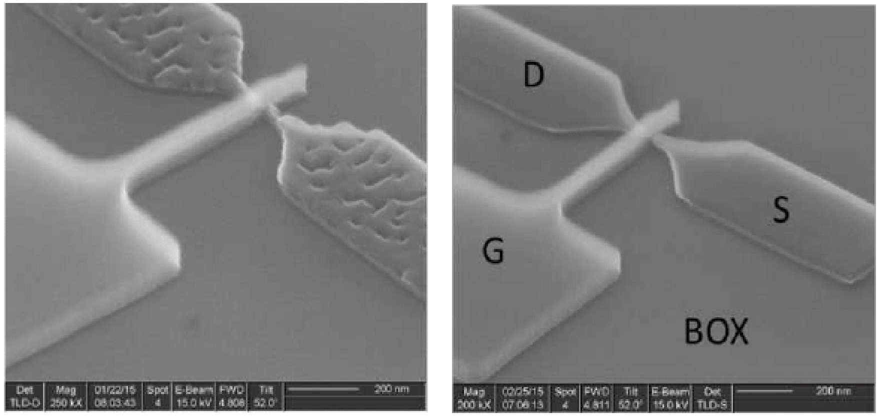
STUDY AND DEVELOPMENT OF ADVANCED SURFACE PREPARATIONS FOR THE INTEGRATION OF NEW MATERIALS IN MICRO/NANOELECTRONICS



WET and Siconi^{TM} cleaning sequences for SiGe pMOS channel

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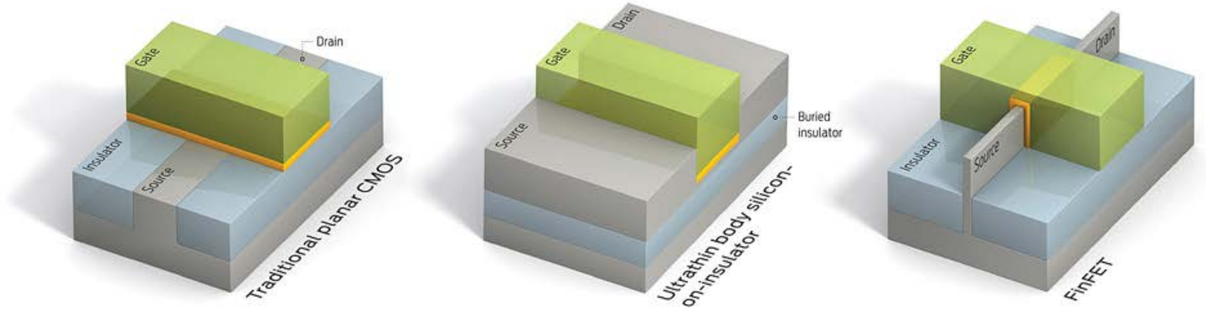
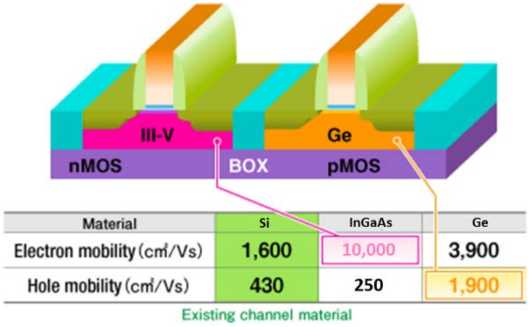
Source : Integration of Low Temperature SiGe:B Raised Sources and Drains in p-type FDSOI Field Effect Transistors. ECS Transactions, 75 (8) 51-58 (2016). The Electrochemical Society

INTRODUCTION



- ➢ **3D architectures** and critical **transistor dimensions** of new devices involve major challenges in terms of surfaces and **lower thermal budget** treatments.

- ➢ Integration of new materials → improve performances:
  - ➢ **SiGe** or **Ge** for pMOS transistor (hole mobility).
  - ➢ **III/V alloys materials** (InGaAS, InAs, AsGa) for nMOS transistor (electron mobility) and photonic applications (direct gap).



Material	Si	InGaAs	Ge
Electron mobility (cm²/Vs)	1,600	10,000	3,900
Hole mobility (cm²/Vs)	430	250	1,900

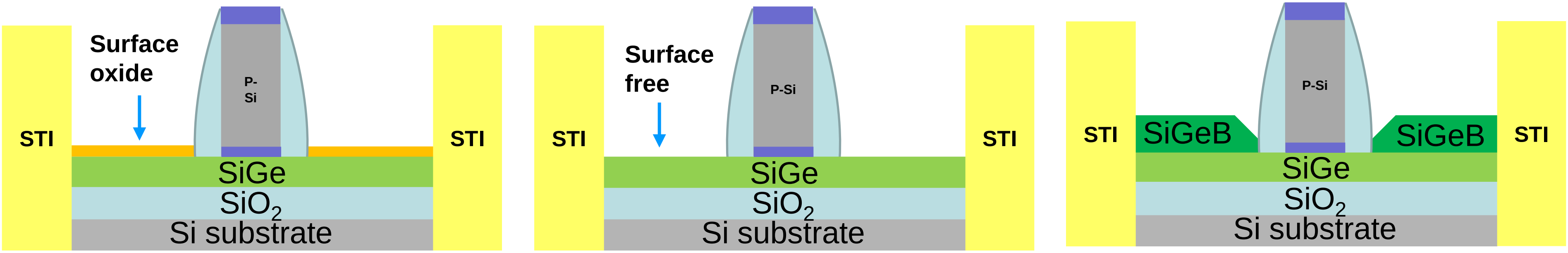
Existing channel material

- ➢ New materials present very reactive surfaces in ambient air → WET and in situ surface treatment combination

http://www.3m.com/3M/en_US/novec/industry-solutions/semiconductor

OBJECTIVE OF THE STUDY

- **SiGe source/drain epitaxial re-growth** :



Surface preparation **WET-DRY** (**Epi-Ready**)

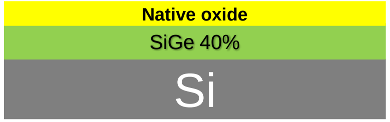
Epitaxy Growth

- **Remove surface oxide**
- **Low Contamination** C, O, N, Cl, F (Epi-killer)
- **Low** Roughness, defectivity, substrate consumption

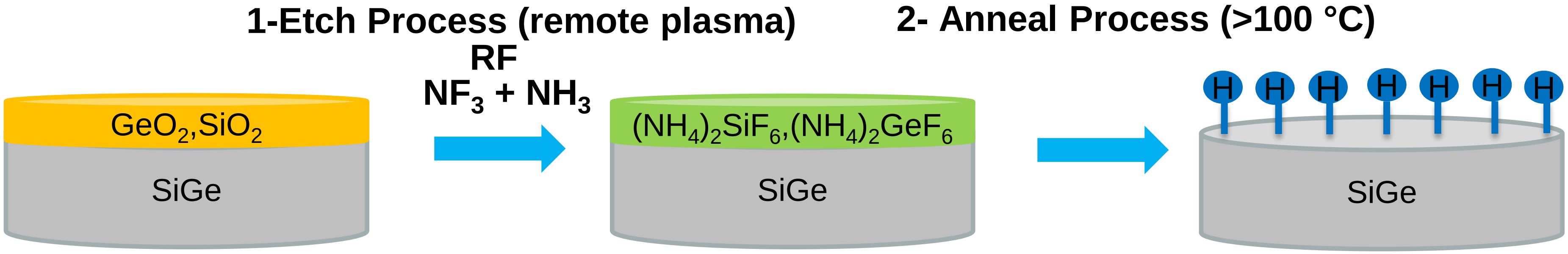
CLEAN ROOM WORKING ENVIRONMENT

Substrate use :

Strained SiGe 40%layers epitaxially grown on Si bulk or SOI (wafer 300 mm)



Siconi principle :



1-Etch Process (remote plasma)

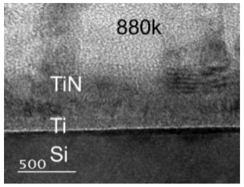
RF

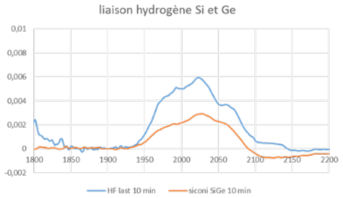
$NF_3 + NH_3$

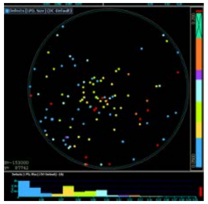
2- Anneal Process (>100 °C)

Characterization :

XPS grazing angle *thermo theta 300*, AFM, ellipsometry, FTIR-ATR and FTIR MIR

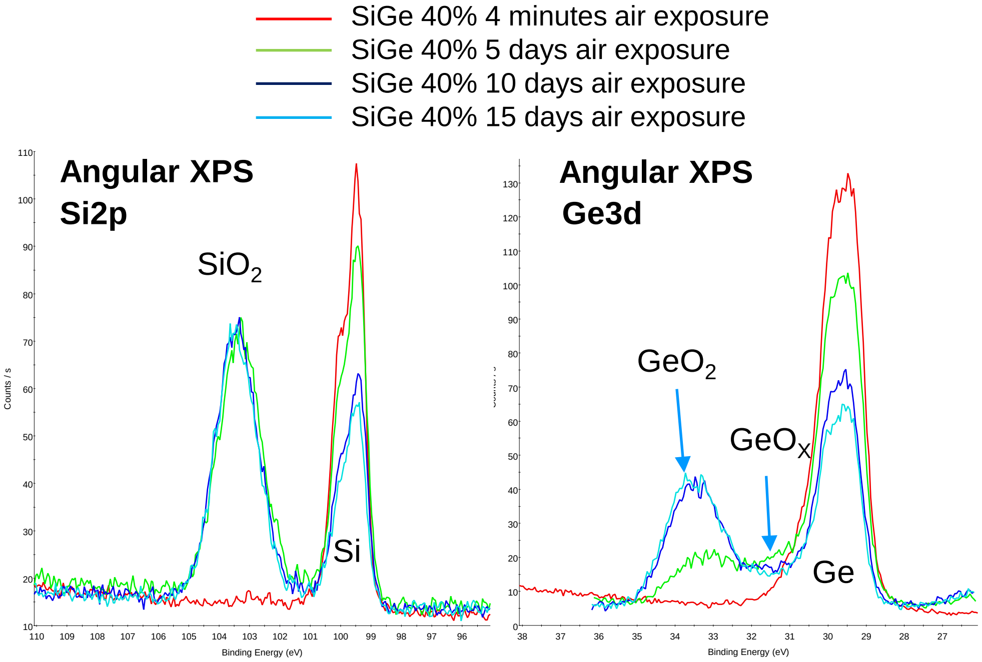



liaison hydrogène Si et Ge

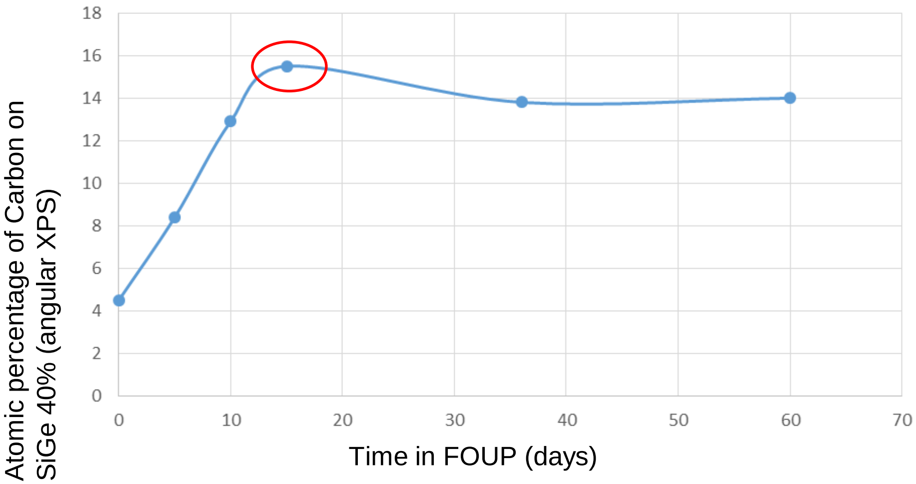


TIME EVOLUTION OF SIGE 40% SURFACE IN AIR

Grazing XPS angular characterization :



Evolution of Carbon contamination on a clean SiGe in clean room atmosphere



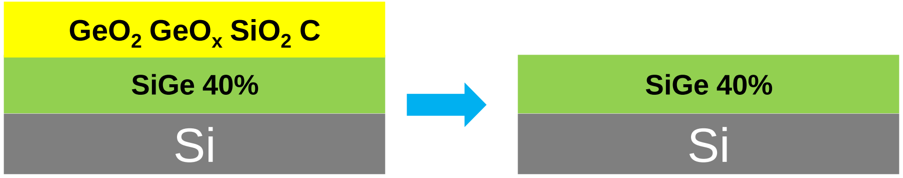
- ➢ Growth of a **mixed oxide** SiO_2, GeO_x and GeO_2 on clean room atmosphere

- ➢ **Carbon contamination increase** on surface substrate

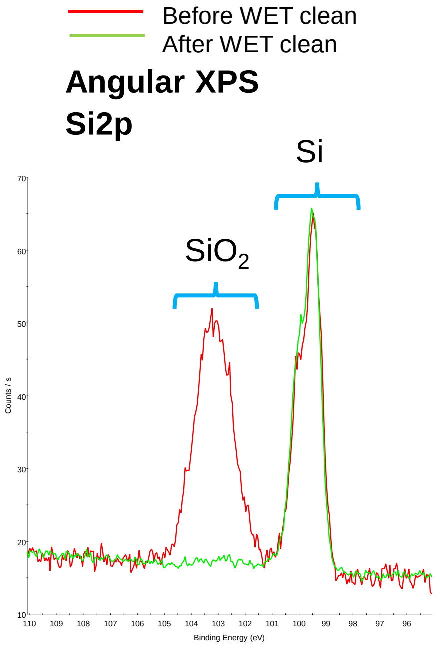
- ➢ Maximum Carbon contamination **after 15 days**

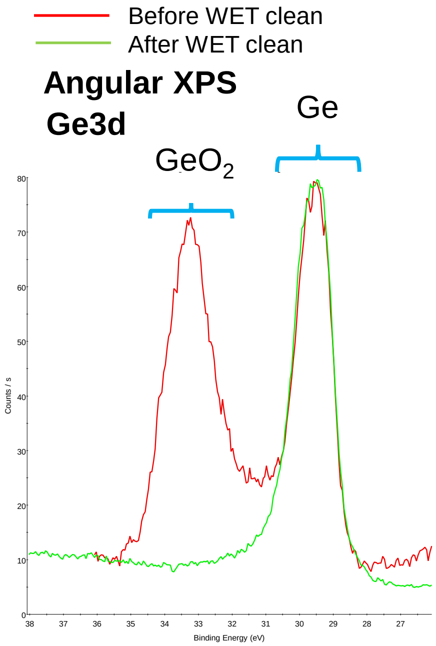
15 days aged sample will be used for cleaning efficiency Characterization

SURFACE PREPARATION WITH HF CHEMISTRY

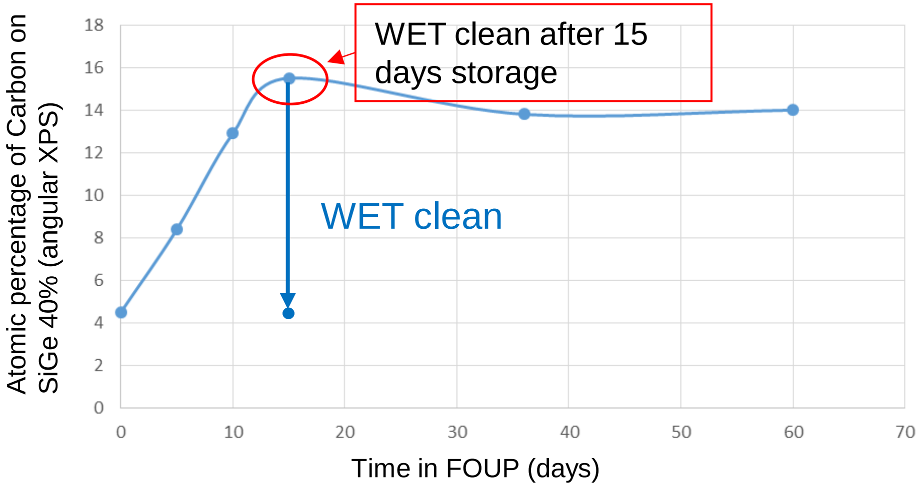


WET clean





Evolution of Carbon contamination on a clean SiGe in clean room atmosphere



Angular XPS Quantification SiGe 40% Before and after WET clean

	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

- **Roughness ≈ 0,2 nm**
- **SiGe consumption ≈ 5 Å**
- **WET cleaning : efficiency toward oxide and C contamination removal**

SURFACE PREPARATION WITH HF CHEMISTRY

GeO_2 GeO_x SiO_2 C

SiGe 40%

Si

WET clean

SiGe 40%

Si

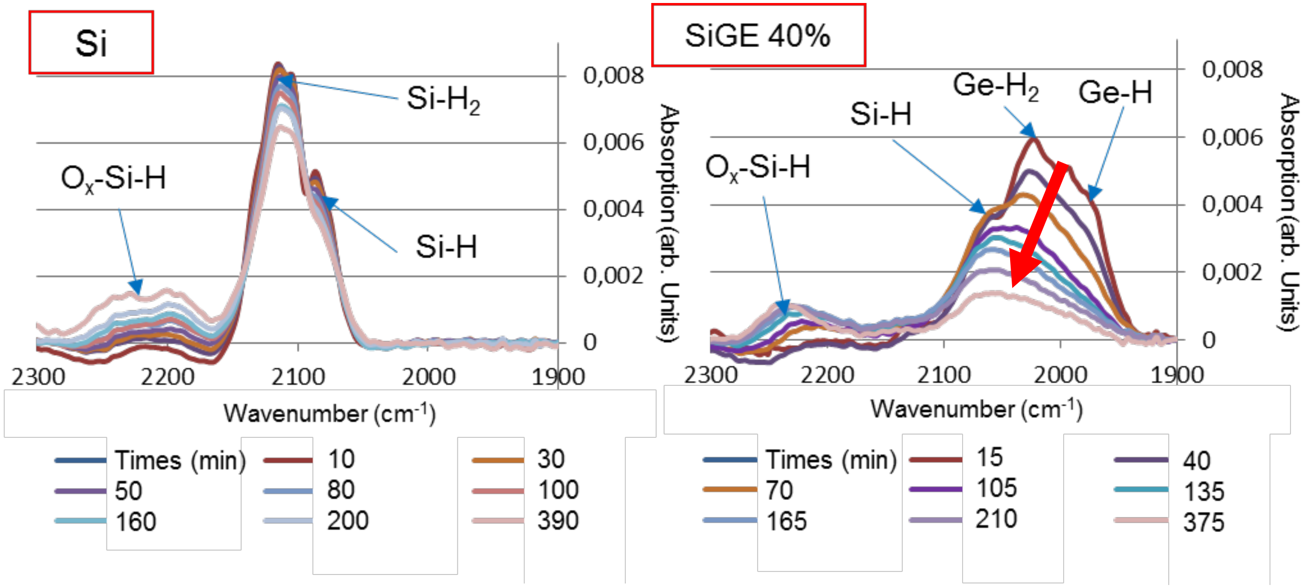
Air break

GeO_2 GeO_x SiO_2 C

SiGe 40%

Si

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

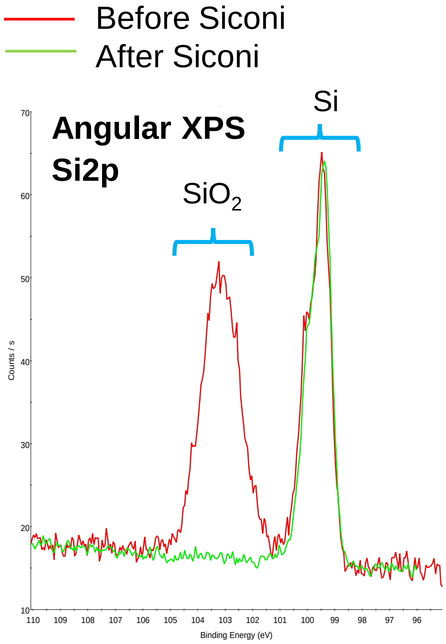


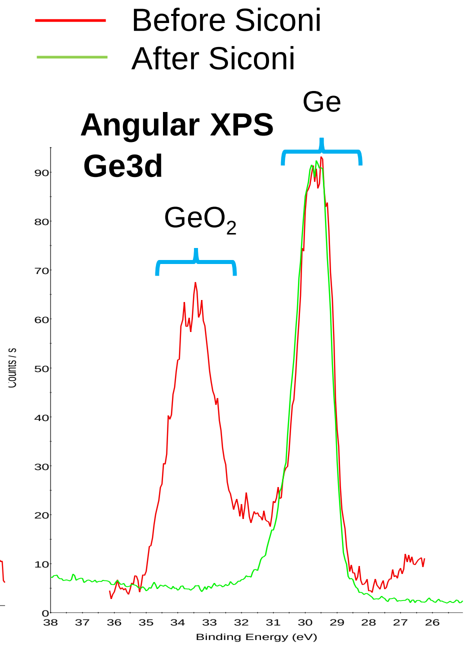
- IV-H bonds decrease after the WET clean in benefit of Si-O bonds
- **SiGe 40%Hydrogen passivation:**
  - **half of the Si-H and Ge-H loss after 2 hours for SiGe40%**
- **Air break can't be managed**

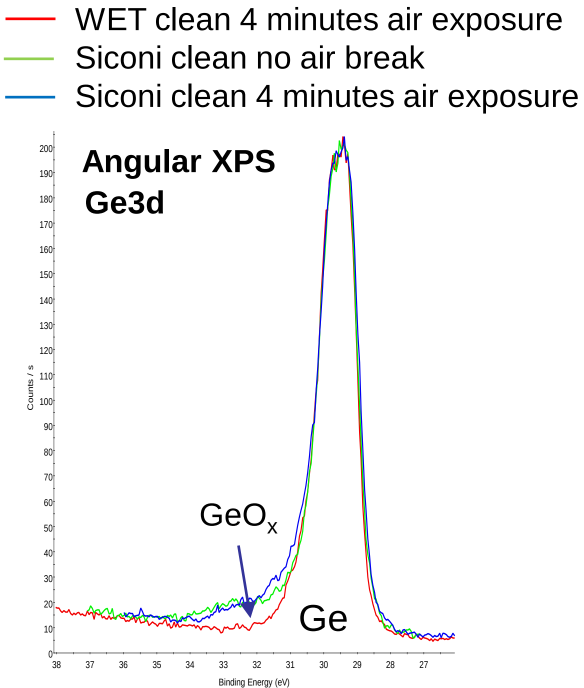
Very fast surface evolution → "in situ" clean mandatory

SURFACE PREPARATION WITH SICONI (IN-SITU)

Siconi and HF comparison :







- ➢ **Roughness ≈ 0,2 nm**
- ➢ **SiGe consumption ≈ 5 Å**
- ➢ **Siconi clean : SiO_2 and GeO_2 removal efficient** 👍
  Less efficient on GeO_x than HF 👎

SURFACE PREPARATION WITH SICONI (IN-SITU)

GeO_2 GeO_x SiO_2 C

SiGe 40%

Si

Siconi clean

SiGe 40%

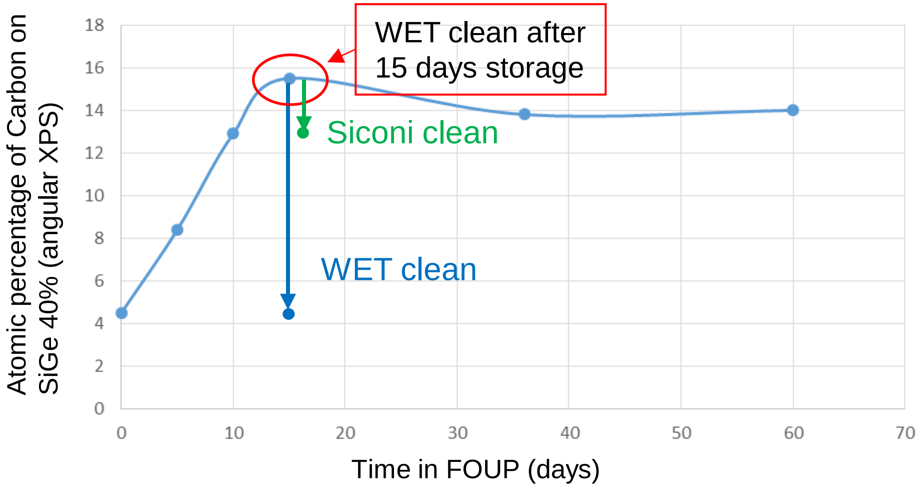
Si

Carbon contamination efficiency:

Angular XPS Quantification SiGe 40% Before and after Siconi clean

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

Evolution of Carbon contamination on a clean SiGe in clean room atmosphere



Siconi doesn’t work on Carbon contamination

HF AND SICONI COMPARISON

- **WET clean (HF removal oxide):**
  - **Efficiency on** GeO_2, SiO_2, GeO_x and C contamination removal 👍
  - **air break incompatible reactive surface** 👎

- **Siconi treatment :**
  - Process in-situ: **no Q-time** 👍
  - **Efficiency on** GeO_2 and SiO_2 👍
  - **Poor efficiency** on **GeO_x** 👎
  - **Inefficient Carbon contamination** 👎

⬇

Alternative cleaning strategy mandatory

ALTERNATIVE STRATEGY PROPOSAL FOR AGED SAMPLE

GeO_2 GeO_x SiO_2 C

SiGe 40%

Si

Aged sample

SiGe 40%

Si

Goal : No oxide and carbon to be epi ready surface

ALTERNATIVE STRATEGY PROPOSAL FOR AGED SAMPLE

GeO_2 GeO_x SiO_2 C
SiGe 40%
Si

Aged sample

Oxide Siconi ready
SiGe 40%
Si

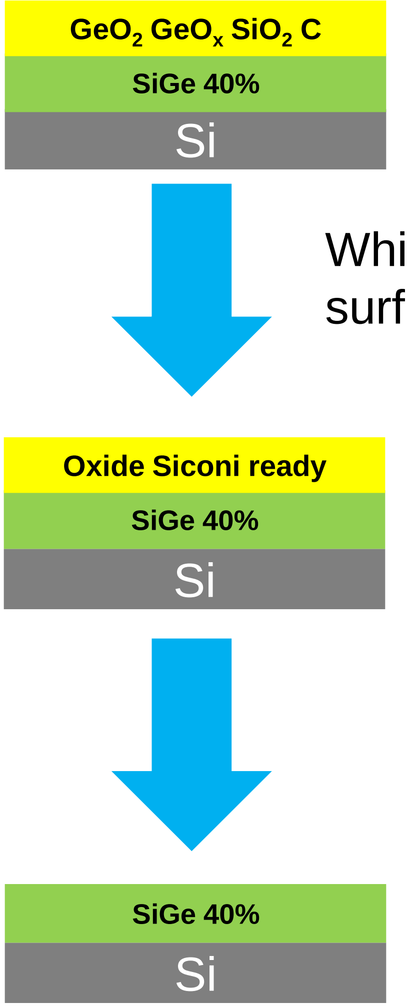
- ➢ No GeO2, GeOx
- ➢ No Carbon contamination

No air break → siconi

SiGe 40%
Si

Goal : No oxide and carbon to be epi ready surface

ALTERNATIVE STRATEGY PROPOSAL FOR AGED SAMPLE



GeO_2 GeO_x SiO_2 C
SiGe 40%
Si

Aged sample

Which wet chemistry can manage the surface composition?

Oxide Siconi ready
SiGe 40%
Si

- ➢ No GeO2, GeOx
- ➢ No Carbon contamination

No air break → siconi

SiGe 40%
Si

Goal : No oxide and carbon to be epi ready surface

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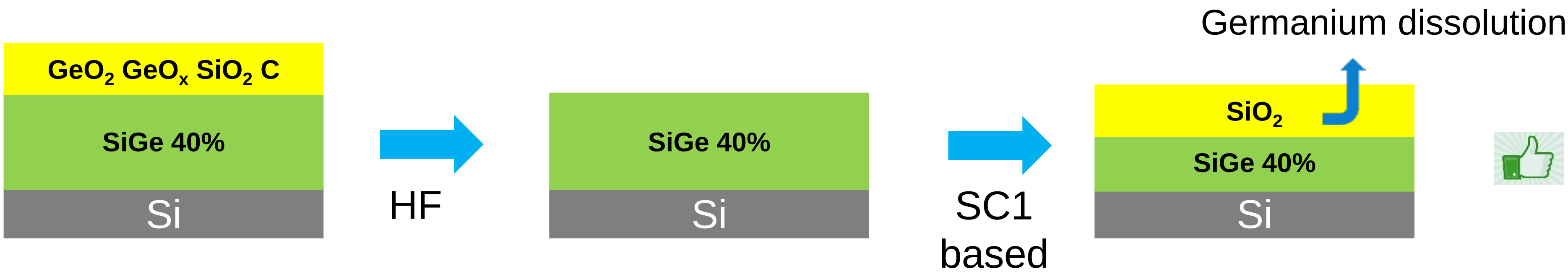
OXIDE COMPOSITION WITH DIFFERENT WET OXIDE

leti
cea tech

Angular XPS Quantification SiGe 40%

	HF-HOT SPM	HF-O_3	HF- HOT SC1	HF-COLD SC1
SiO_2% (Si2p)	21,4	18,5	21,5	18
GeO_2% (Ge3d)	2,1	1,8	N.D.	N.D.
C% (C1s)	1,6	3,5	1,6	N.D.
Oxide Thickness nm	1,96	1,45	1,8	1,3
	👎	👎	👍	👍

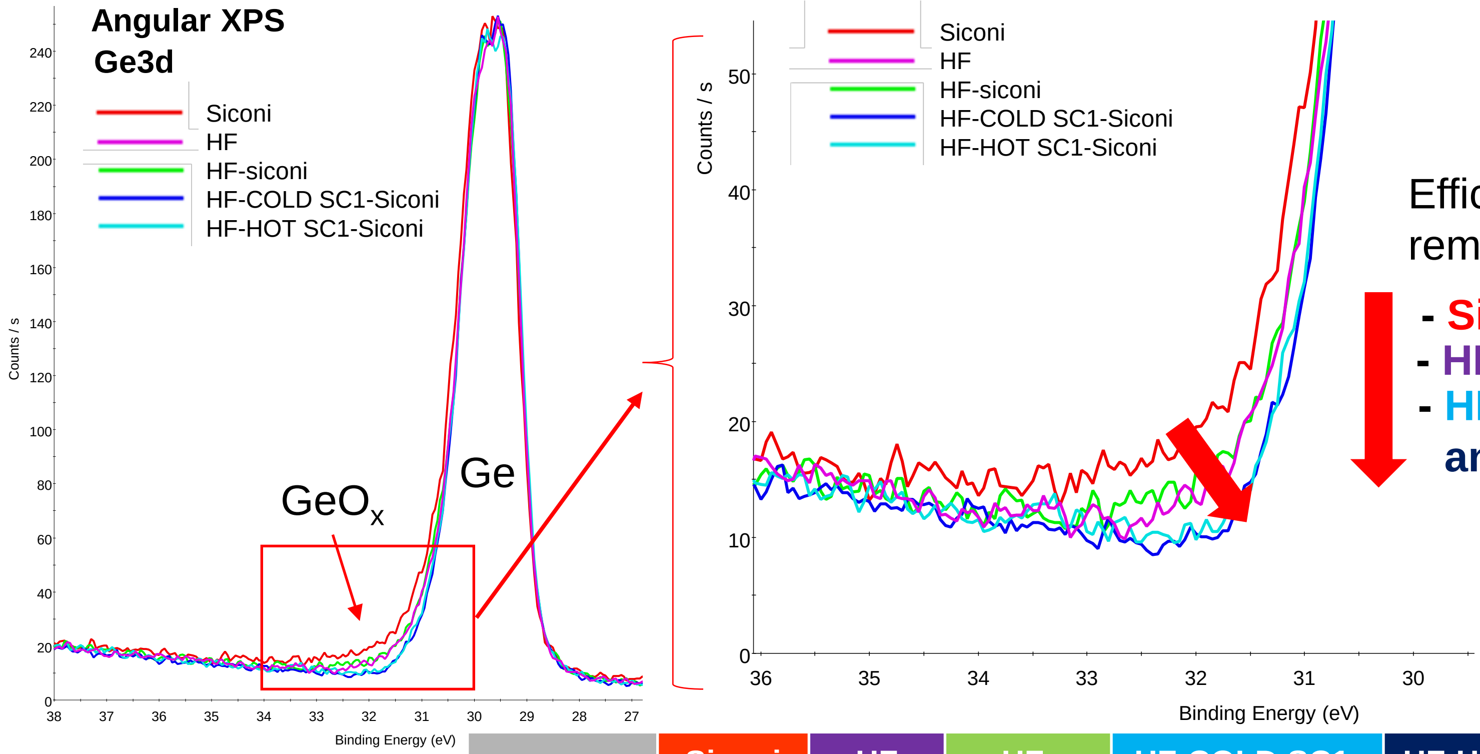


- ➢ **Roughness <0,2nm**
- ➢ **GeO_2 dissolution with HOT SC1 and COLD SC1 (SiO_2 oxide growth)**
- ➢ **Low carbon contamination**

➡ **HOT SC1 and Cold SC1 chemical oxide pre-siconi**

👍

WET AND SICONI ASSOCIATION CLEANING



Efficiency on GeO_x removal :

- **Siconi only**
- **HF** and **HF-Siconi**
- **HF-COLD SC1-siconi and HF-Hot SC1-Siconi**

Angular XPS Quantification SiGe 40%

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

Efficiency on Oxygen and Carbon removal

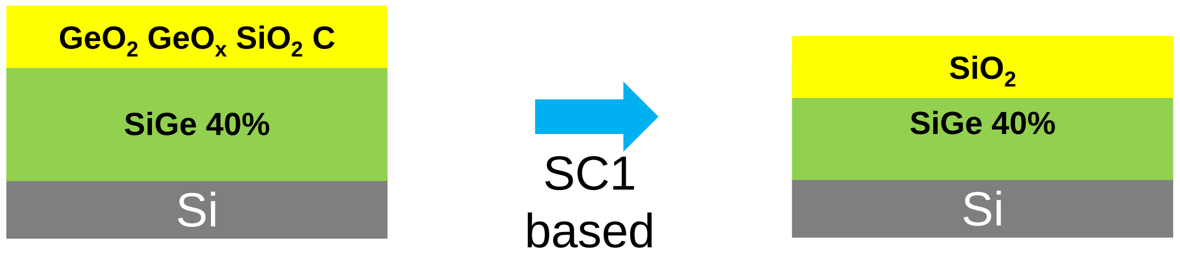
- **HF-COLD SC1-Siconi**
- **HF-HOT SC1-Siconi**

Best Epi ready surface

HF mandatory ???

WET (WITHOUT HF) AND SICONI ASSOCIATION CLEAN

SC1 clean only direct on aged sample



HF remove the native oxide before the SC1

WET oxide clean without the native oxide removal

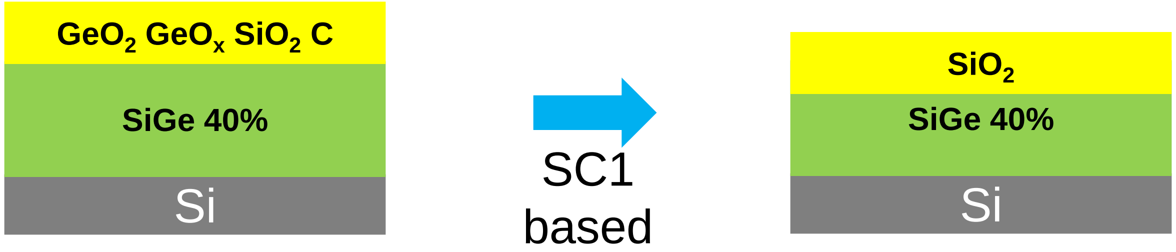
Angular XPS Quantification SiGe 40%

	NATIVE OXIDE	HF- HOT SC1	HF-COLD SC1	HOT SC1	COLD SC1
SiO_2 % (Si2p)	**14,8**	**21,5**	**18**	**22,3**	**21,4**
GeO_2 % (Ge3d)	**5,4**	**N.D.**	**N.D.**	**N.D.**	**1,3**
C % (C1s)	**15,5**	**1,6**	**N.D.**	**N.D.**	**9,1**

Cold SC1not efficient enough on :
- GeO_2 Dissolution
- Carbon contamination

WET (WITHOUT HF) AND SICONI ASSOCIATION CLEAN

SC1 clean only direct on aged sample



HF remove the native oxide before the SC1

WET oxide clean without the native oxide removal

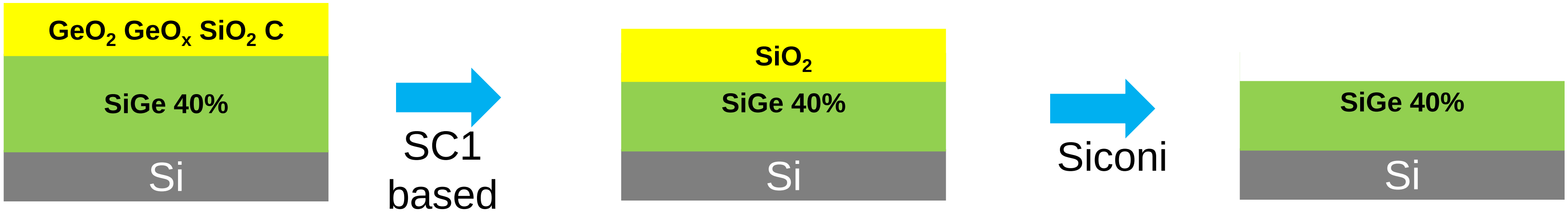
Angular XPS Quantification SiGe 40%

	NATIVE OXIDE	HF- HOT SC1	HF-COLD SC1	HOT SC1	COLD SC1	COLD SC1 (Times treatment longer)
SiO_2 % (Si2p)	14,8	21,5	18	22,3	21,4	17
GeO_2 % (Ge3d)	5,4	N.D.	N.D.	N.D.	1,3	N.D
C % (C1s)	15,5	1,6	N.D.	N.D.	9,1	5,6
		👍	👍	👍	👍 / 👎	👍

- SC1 based mixture alone can manage germanium oxide and carbon
- HF STEP can be removed if consumption fine tuning is mandatory

WET (WITHOUT HF) AND SICONI ASSOCIATION CLEAN

SC1 + Siconi on aged sample



Angular XPS Quantification SiGe 40%

	HF	Siconi	HF- HOT SC1-Siconi	HF-COLD SC1-Siconi	COLD SC1-Siconi	HOT SC1-Siconi
O % (O1s)	8.2	10,4	N.D.	N.D	N.D.	N.D.
C % (C1S)	3.2	10,8	N.D.	N.D.	4.2	4.4
	👎	👎	👍	👍	👍	👍

- **SC1 based mixture + siconi permit very good epi ready surface**

CONCLUSION

conclusion

- **Siconi** and **HF** remove **GeO_2** and **SiO_2** 👍
- Inefficiency of **Siconi** / **Carbon** contamination 👎
- lower efficient of Siconi on **GeO_x** 👎
- **SC1 based mixture** WET cleanings :
  - can **manage germanium oxide** and **carbon** (Siconi –ready) 👍
  - **HF STEP** can be removed if **consumption fine tuning is mandatory**
- **SC1 based mixture + Siconi :**
  - permit very good **epi ready surface** 👍

Perspectives :

- Epitaxy growth of Si on SiGe with WET-Siconi clean
  - Contamination quantification (SIMS)
  - Morphological quality (DRX, AFM…)

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