Surface Preparation and Wet Cleaning for Germanium Surface

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Outline

- **Introduction**
  - Key Cleaning Steps
  - Challenges on Wet Cleaning of SiGe and Ge
- **Ge Surface Preparation**
  - PRE (Particle Removal Efficiency)
  - MRE (Metal Removal Efficiency)
- **Material Removal Selective to SiGe/Ge**
  - Unreacted Ni Removal
- **Controlled SiGe/Ge Wet Etch**
  - SiGe Wet Etch Selective to Ge
- **Summary**

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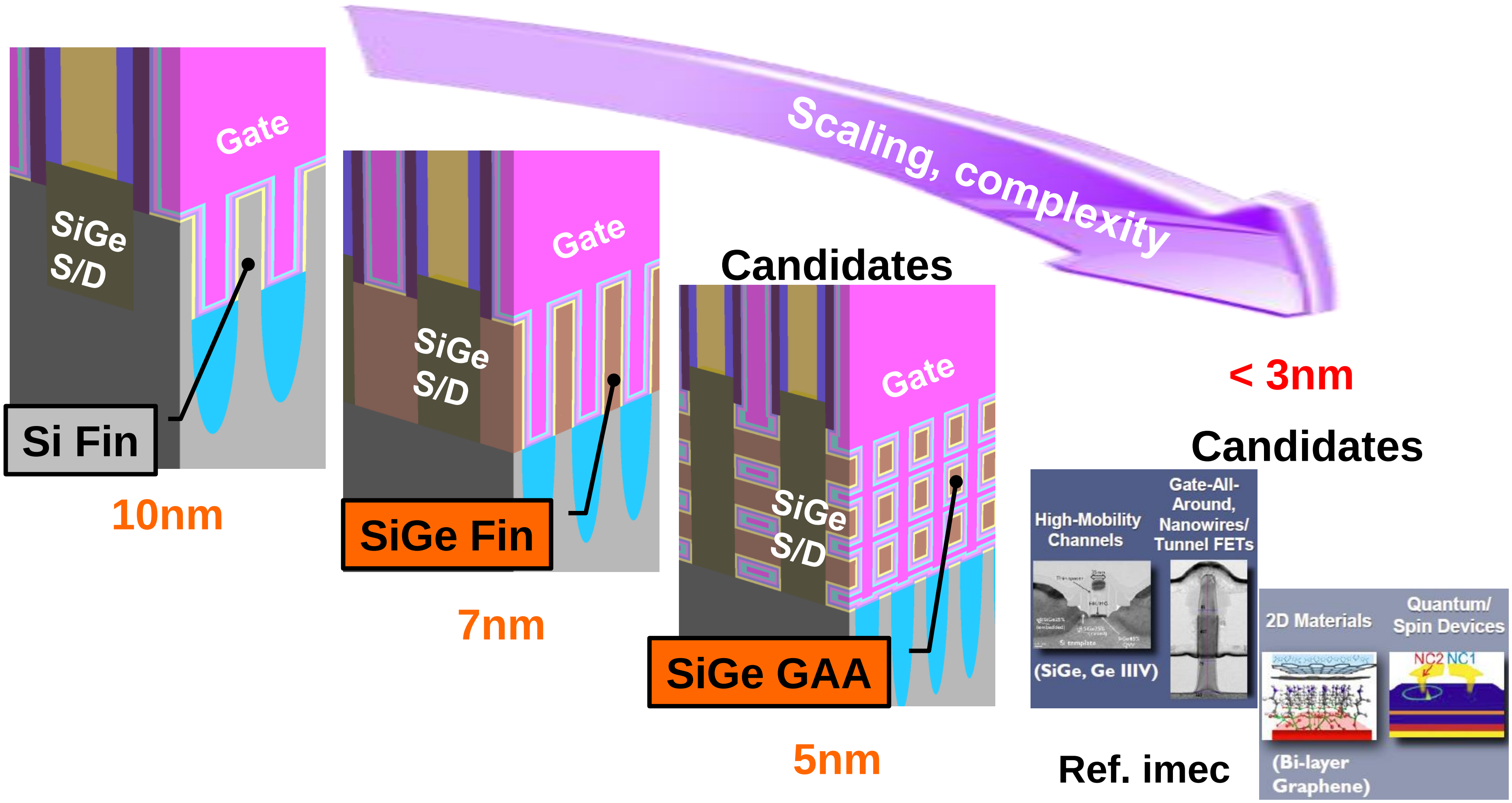
Assumed Logic Device Fabrication



Ref. imec

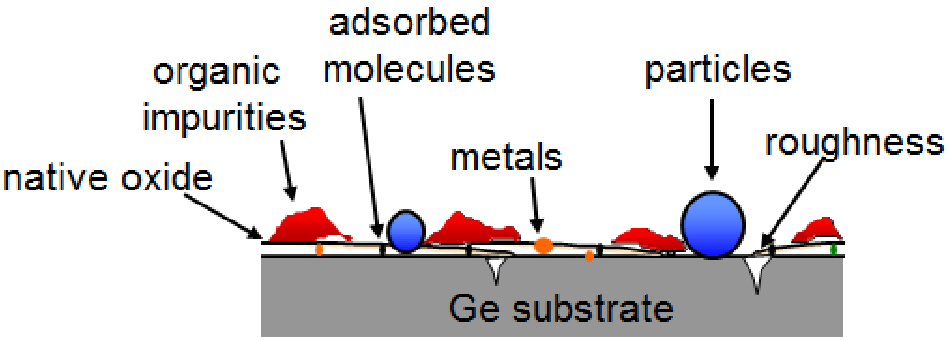
❑Structure becomes more complex while scaling down

❑New materials as SiGe, Ge and III-V will be introduced

Key Cleaning Steps on Ge

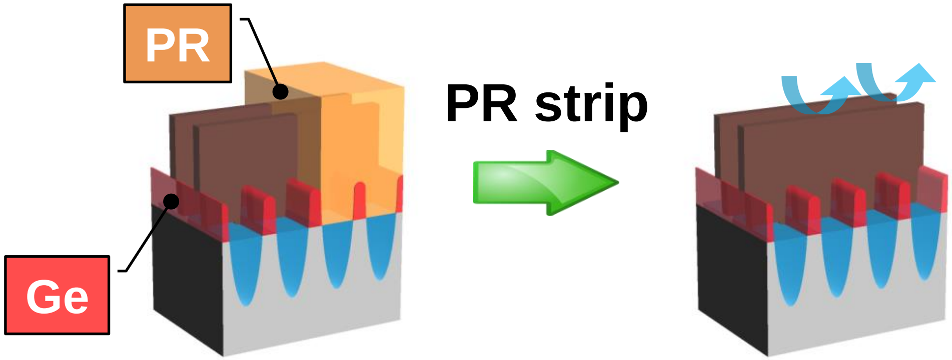
Surface preparation

- Post etch clean
- Pre-epi clean



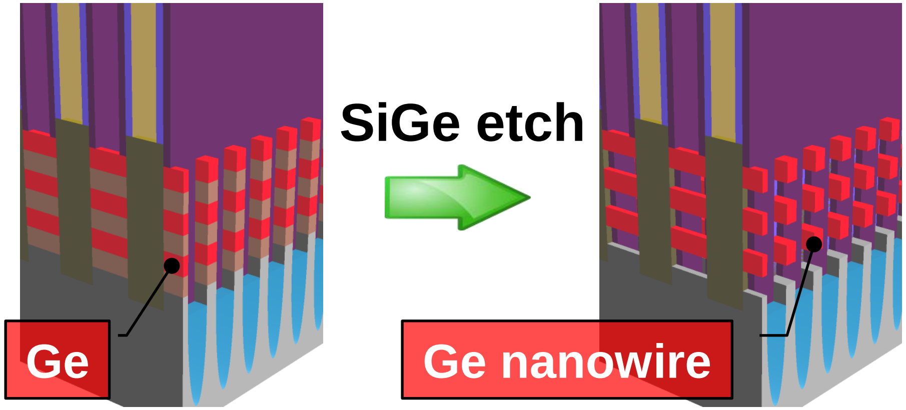
Material removal

- PR strip
- Unreacted Ni removal

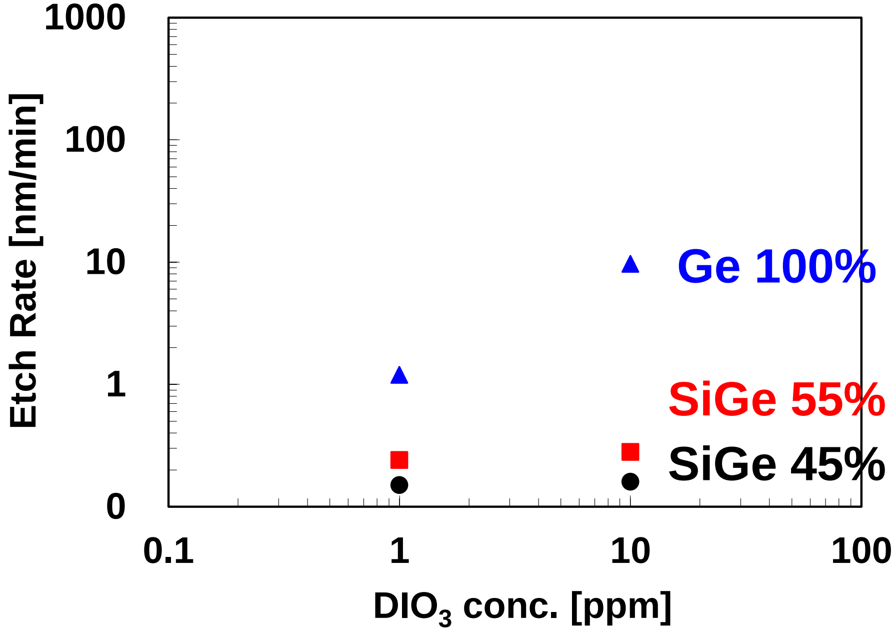


Controlled SiGe/Ge etch

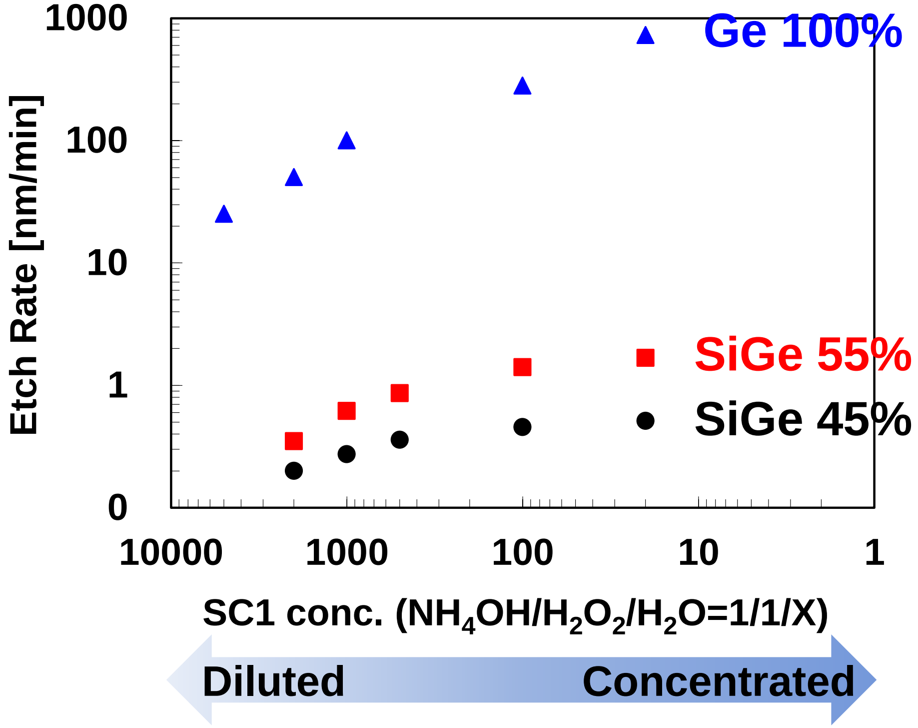
- Controlled Ge-Fin Trimming
- Selective SiGe etch for GAA



Challenges on Wet Cleaning of SiGe/Ge



SiGe/Ge loss in DIO$_3$



SiGe/Ge loss in SC1

[M.Wada et al., *Solid State Phenomena* 187 (2012) 19]

❑Ge is easily dissolved in oxidizing solutions, i.e. SC1, DIO$_3$

❑Ge loss management is mandatory

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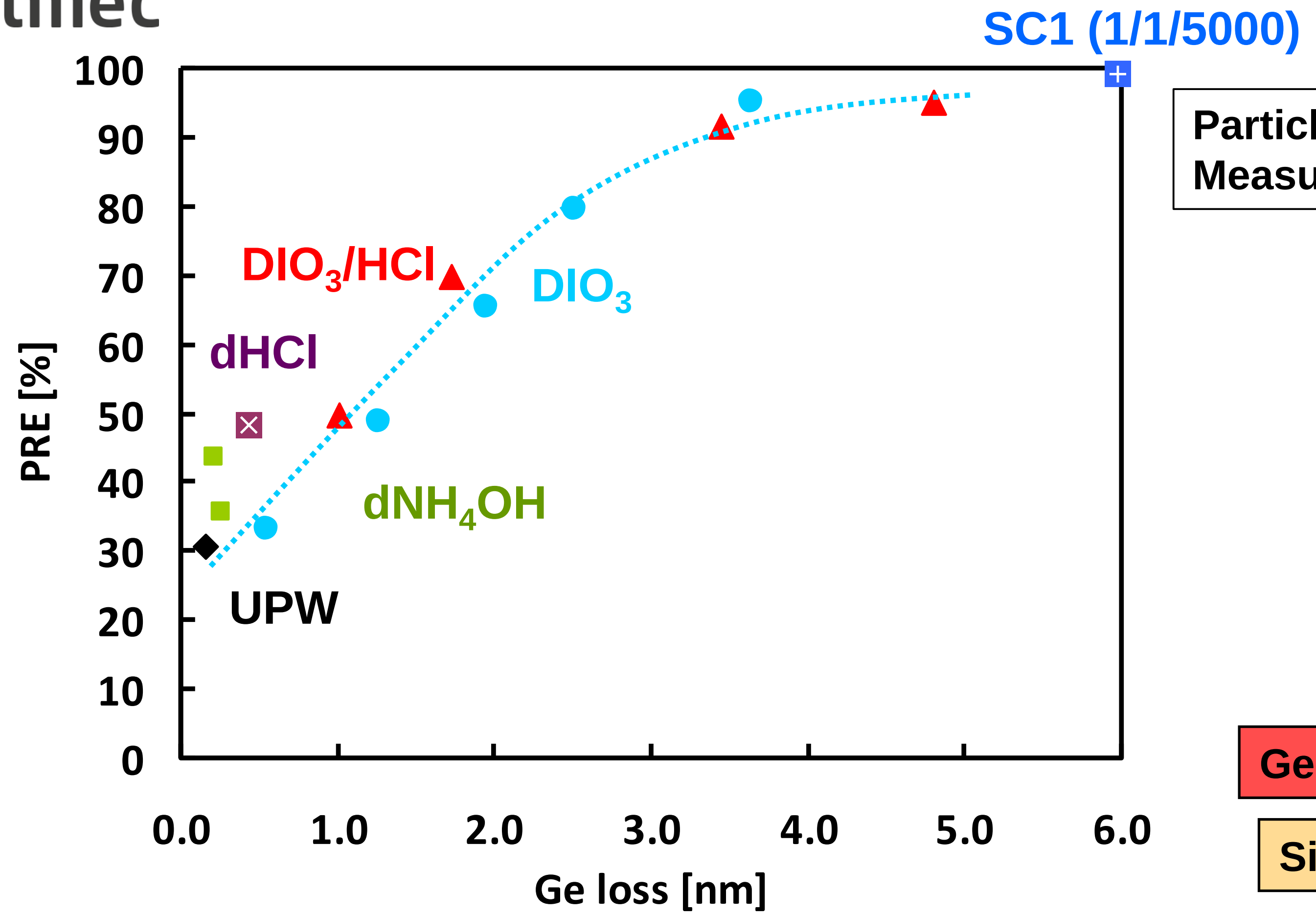
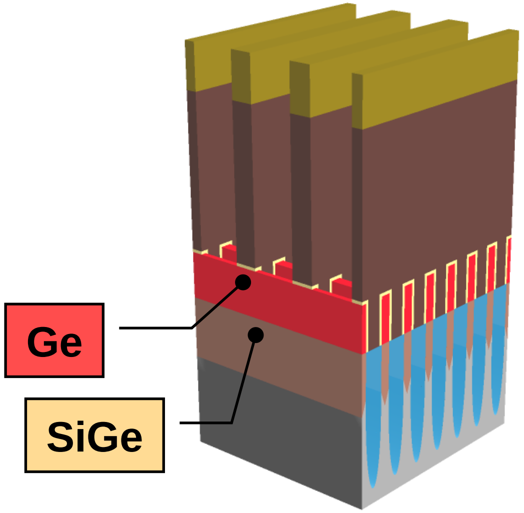
PRE on Ge with Conventional Chemistries



[H.Takahashi et al., *ECS Transactions* 2011 41(5), 163-170]

Particle: 30nm SiO_2-Slurry
Measurement: SP2, Haze

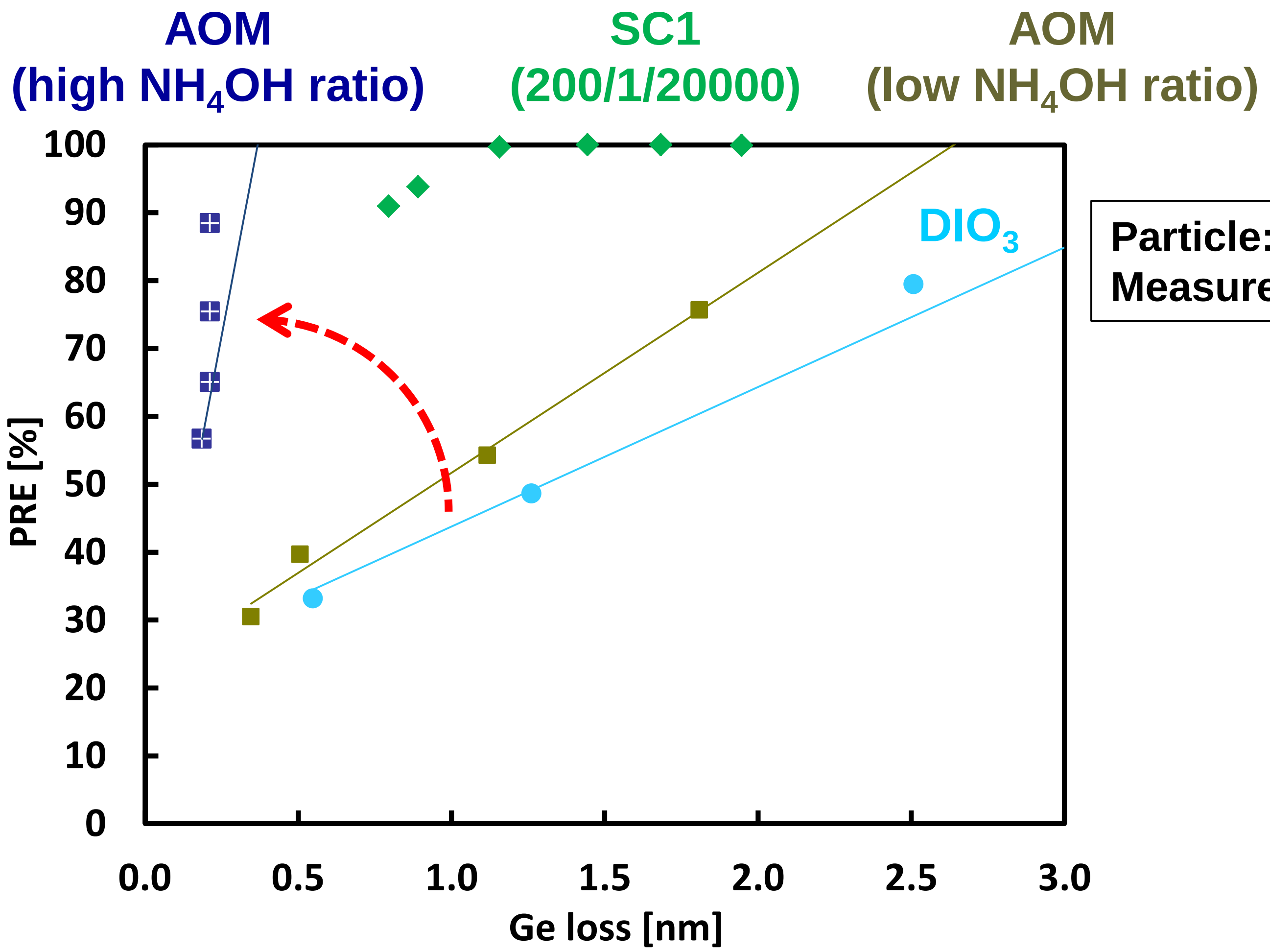
Applicable process:
Post gate etch clean



❑Surface lift-off by oxidizing chemistry is the dominant factor for sufficient particle removal

❑> 3nm Ge etch for > 90% PRE with conventional chemistries

AOM (Ammonia/DIO$_3$ Mixture) for Ge Clean

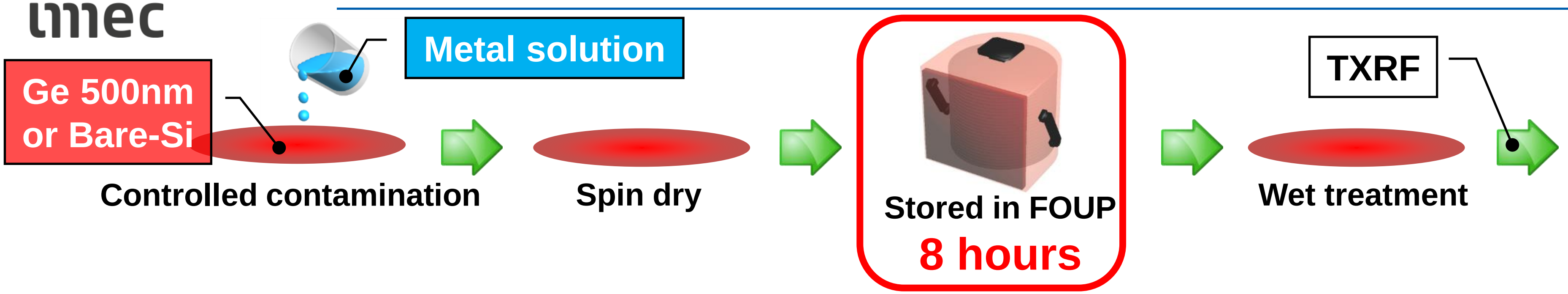


Particle: 30nm SiO$_2$-Slurry
Measurement: SP2, Haze

[H.Takahashi et al., *ECS Transactions* 2011 41(5), 163-170]

❑High PRE with lower Ge loss is obtained by using a clean with AOM, especially in high pH condition

MRE on Ge Surface



Ge 500nm or Bare-Si

Metal solution

Controlled contamination

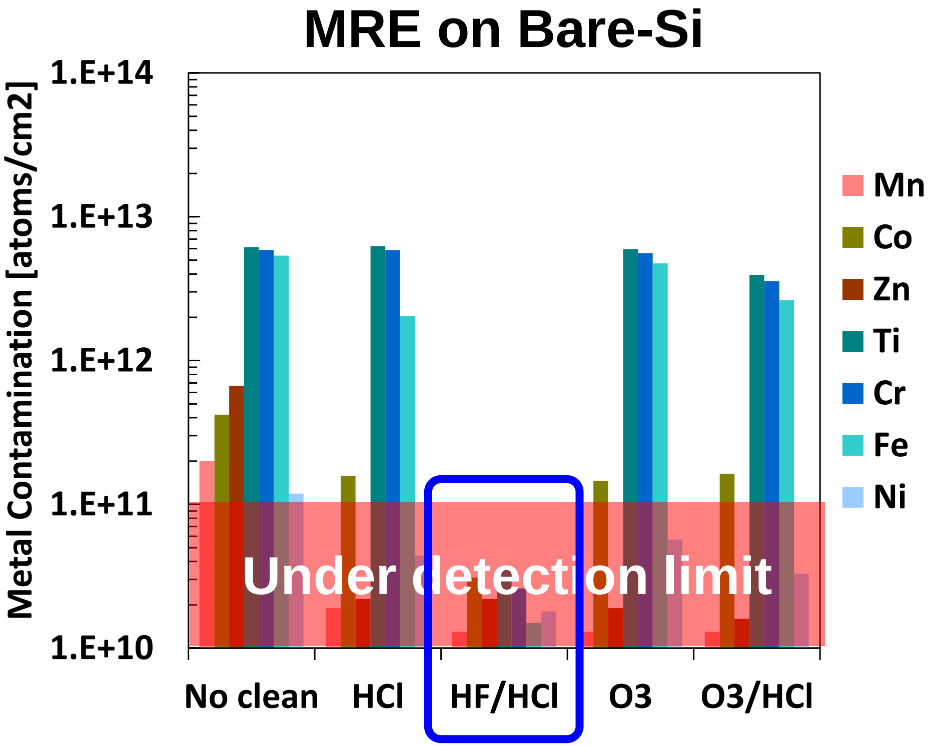
Spin dry

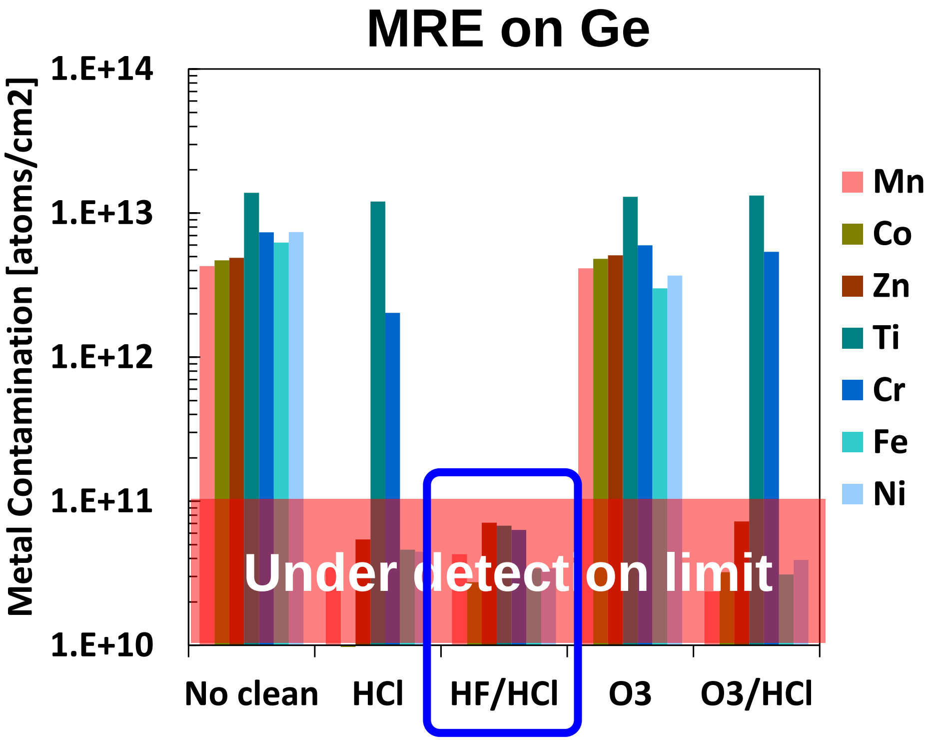
Stored in FOUP

8 hours

TXRF

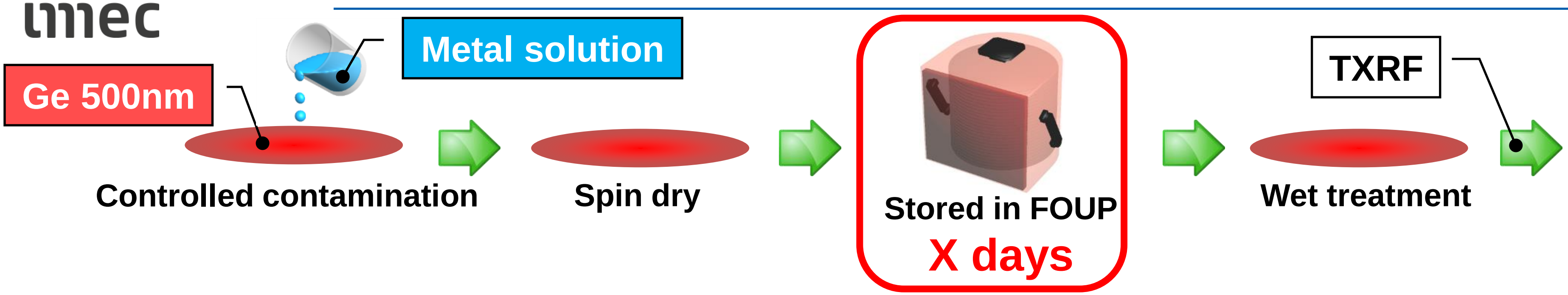
Wet treatment

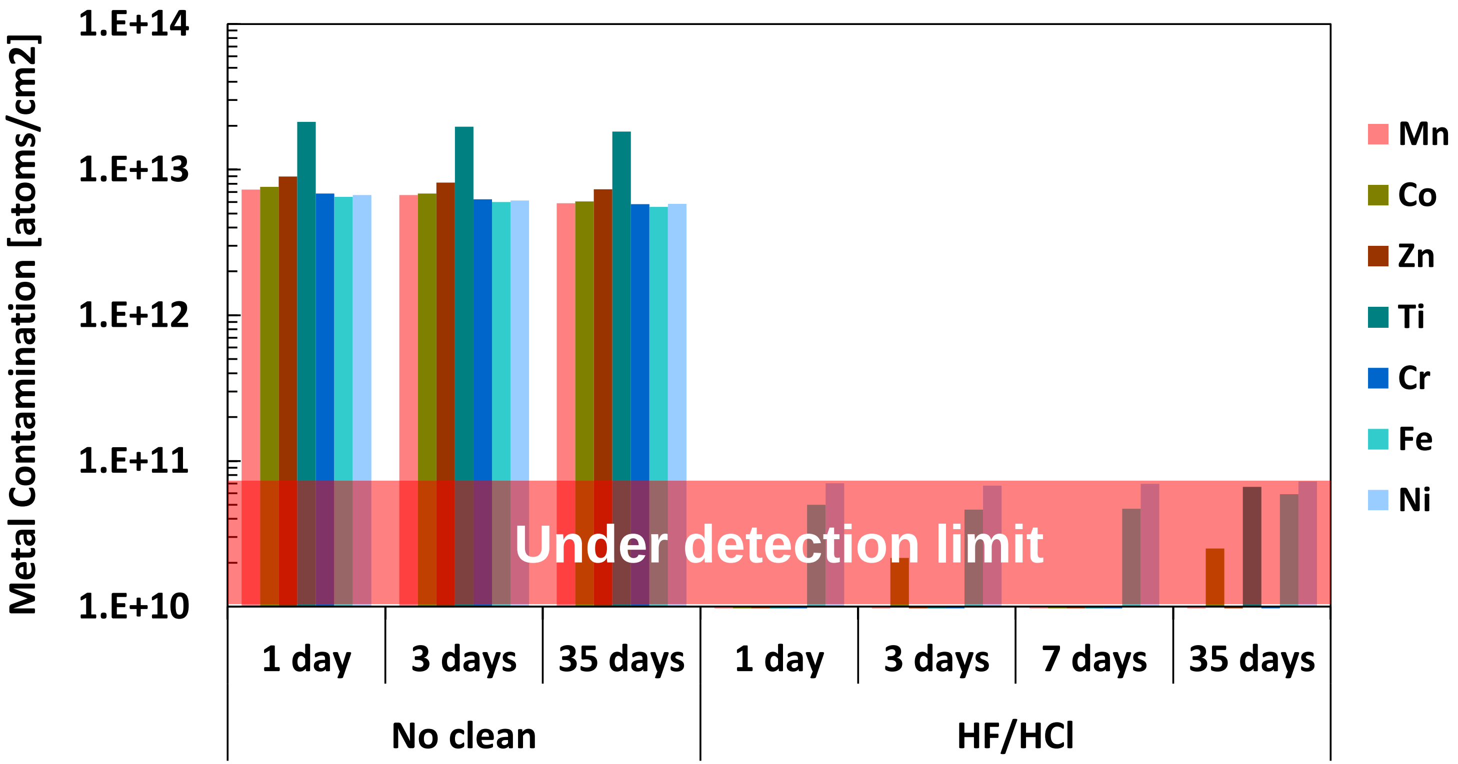




❑HF/HCl performs best: Same trend observed for Si and Ge surfaces, Native oxide removal by HF + Metal dissolution by HCl

Aging Effect on MRE on Ge Surface





- ❑No aging effect on MRE with HF/HCl even after 1 month

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Summary for Surface Preparations on Ge

- **Recommended cleaning combination**
  - For particles: AOM (NH_4OH/DIO_3 mixture)
  - For metals: HF/HCl mixture

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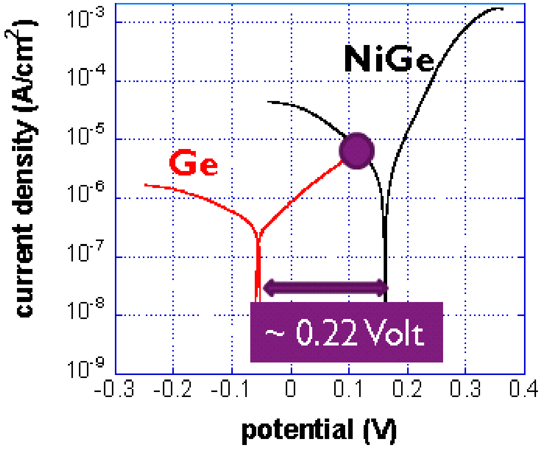
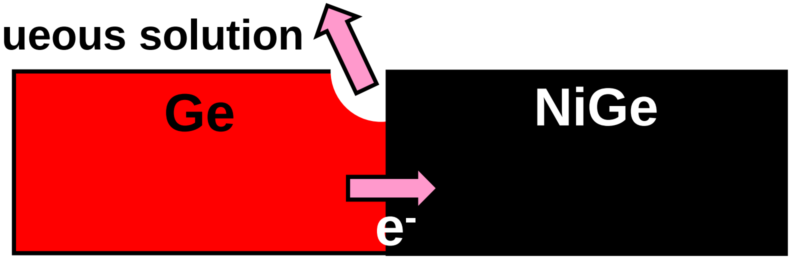
Challenge & Approach for Galvanic Corrosion

One example: Ge corrosion during wet Ni removal using dHCl



GeO dissolves in aqueous solution



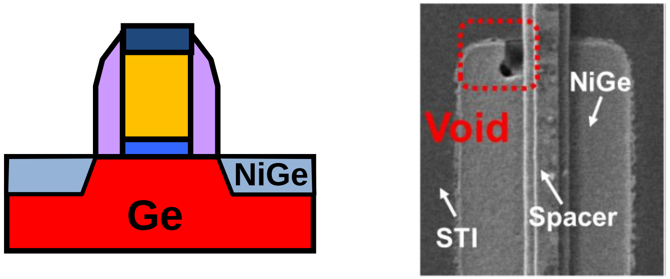
Anode:

$Ge + ½\ O_2 \rightarrow GeO + e^-$

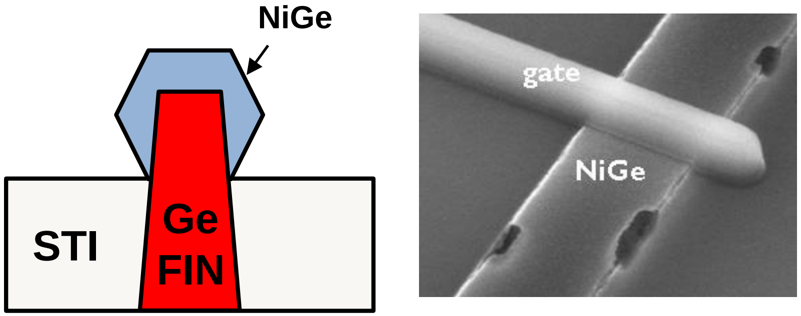
Cathode:

$H^+ + e^- \rightarrow H_2$

$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$



Ge planar device

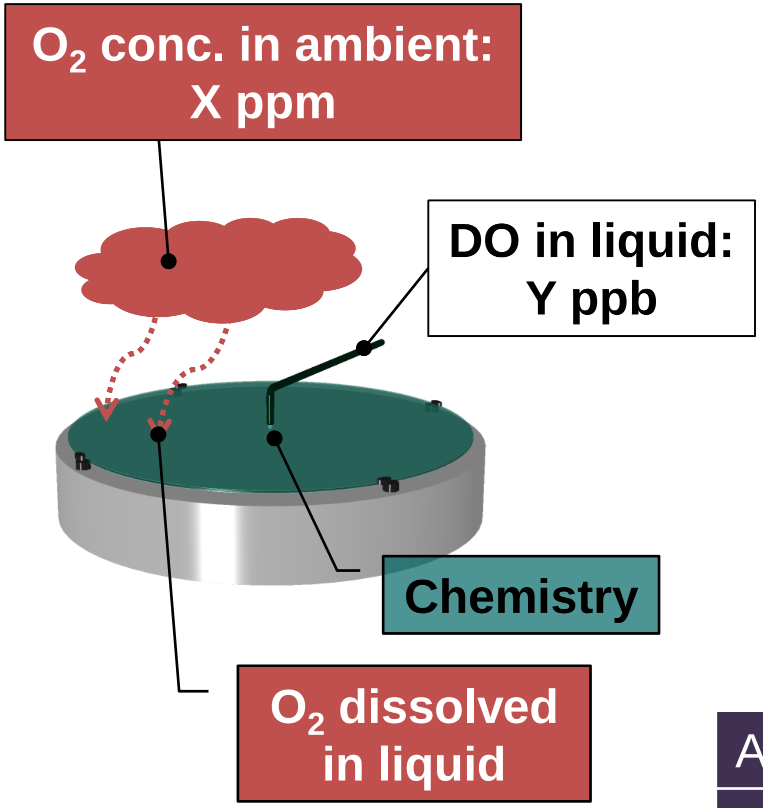


Ge-FinFET device

[F.Sebaai et al., *Solid State Phenomena* 219 (2014) 105-108]

- ❑**Exposure of Ge & NiGe to the cleaning solution during Ge integration**

Management of Low-O_2 Processing

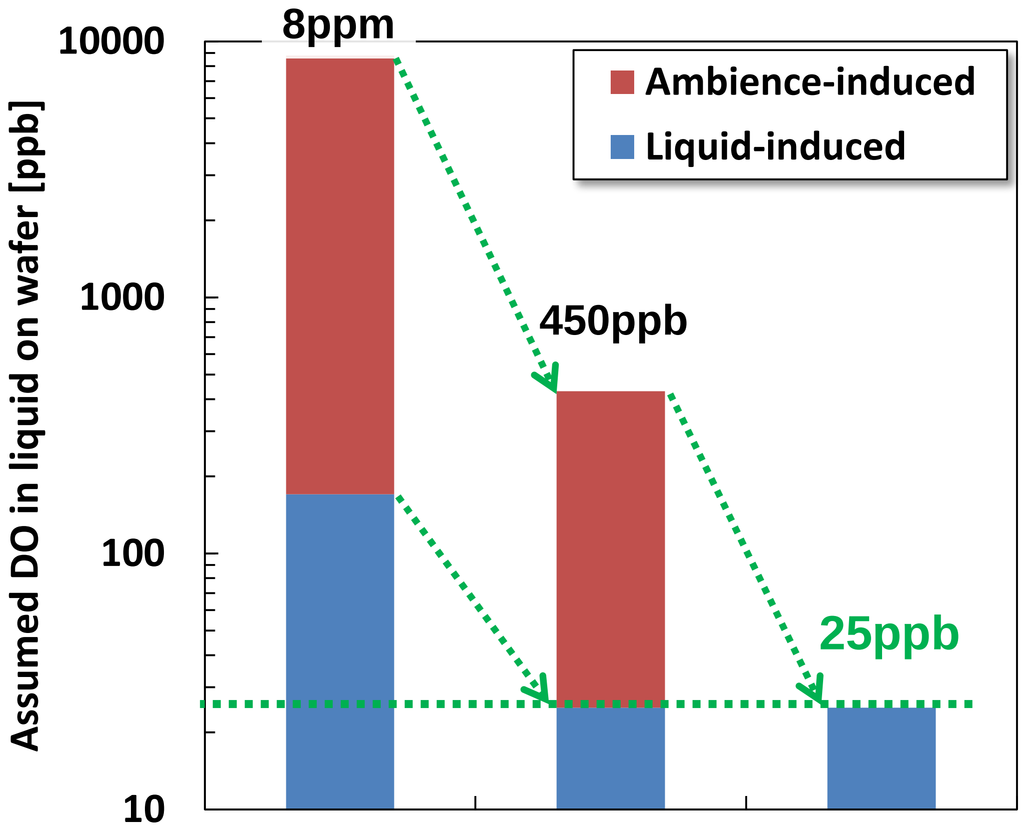


O_2 conc. in ambient:
X ppm

DO in liquid:
Y ppb

Chemistry

O_2 dissolved
in liquid



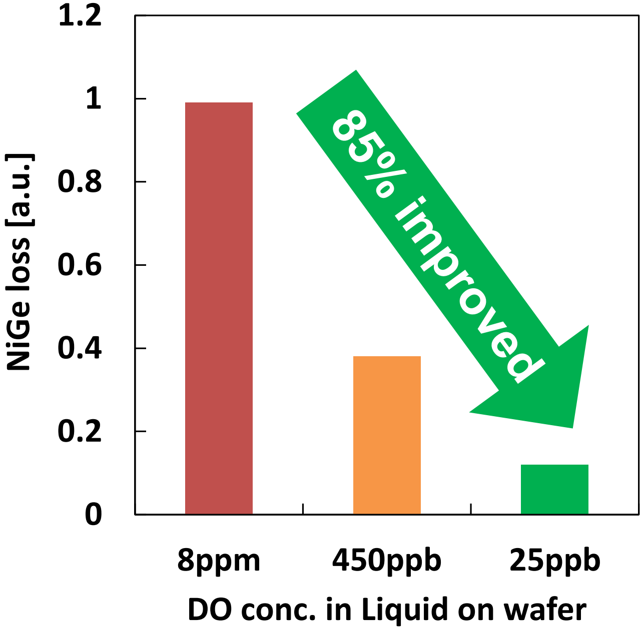
Ambient	20%	1%	10ppm
DO in liquid	170ppb	25ppb	25ppb

[Y.Yoshida et al., *Solid State Phenomena* 219 (2014) 85-88]

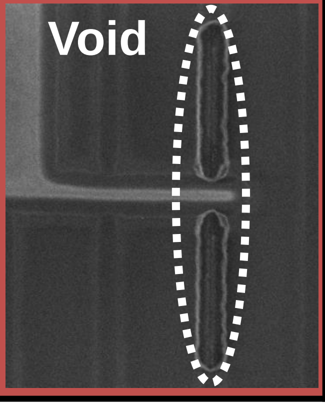
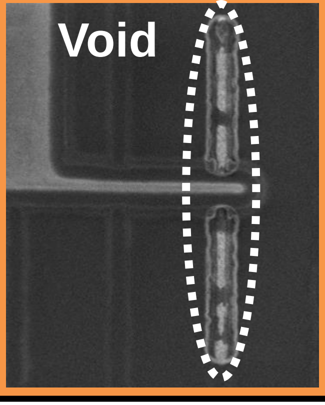
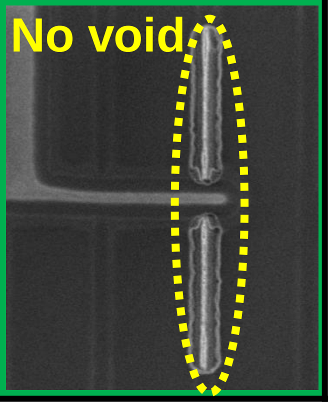
☐ Ambient control allows to achieve low DO condition (<25ppb) in process liquid on wafer

Selective Ni Removal on Ge-FinFET

NiGe loss with HCl



Void occurrence dependency on DO in HCl

DO	8ppm	450ppb	25ppb
SEM image	 Void	 Void	 No void

Void occurrence reduced

[Y.Yoshida et al., *Solid State Phenomena* 219 (2014) 85-88]

❑Void occurrence can be suppressed by the control of the oxygen concentration in liquid & ambient

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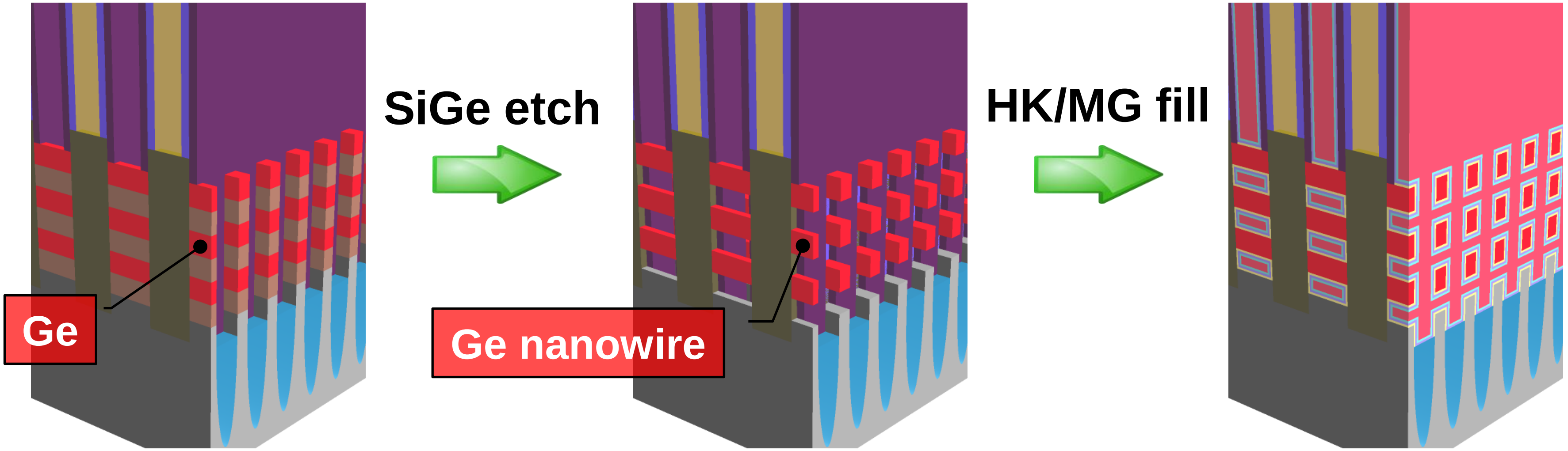
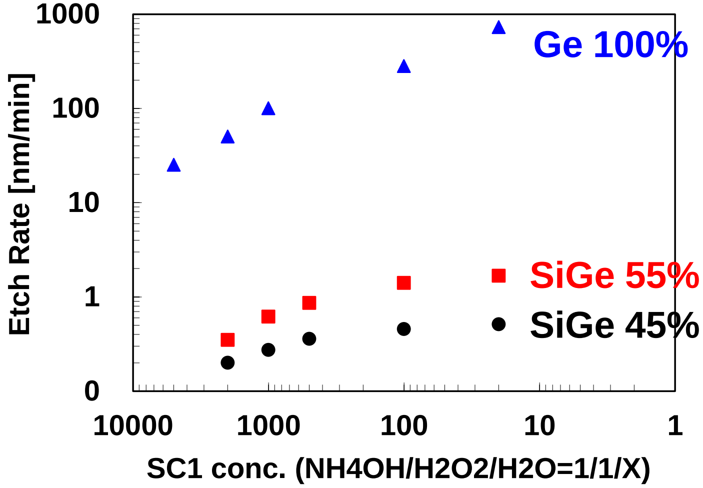
SiGe Wet Etches Selective to Ge



GAA (Gate All Around)

SiGe/Ge loss in SC1



Ge is too sensitive

☐ **Conventional chemistries don’t work on this application**

❑**More study is needed on this kind of applications**

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Summary

◆ SiGe/Ge Surface Preparation

- ☺ Particle removal on Ge surface
  - AOM is recommended for particle removal steps
    - 0.4 nm etch of Ge to achieve ~100% PRE
- ☺ Metal removal for overall cleaning applications:
  - Sufficient removal confirmed by HF/HCl mixture cleaning

◆ Material Removal Selective to SiGe/Ge

- ☺ Unreacted Ni removal
  - Low-O_2 is promising to full Ni remove without Ge corrosions

◆ Controlled SiGe/Ge Wet Etch

- 😐 SiGe wet etch selective to Ge
  - Need more study

Fit your needs, Fit your future

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