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
Introduction

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Summary
Assumed Logic Device Fabrication

Structure becomes more complex while scaling down
New materials as SiGe, Ge and III-V will be introduced

Candidates

< 3nm

Si Fin
10nm

SiGe Fin
7nm

SiGe GAA
5nm

Ref. imec
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

- Ge is easily dissolved in oxidizing solutions, i.e. SC1, DIO₃
- Ge loss management is mandatory

*M.Wada et al., Solid State Phenomena 187 (2012) 19*
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Summary
Surface lift-off by oxidizing chemistry is the dominant factor for sufficient particle removal

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

Particle: 30nm SiO₂-Slurry
Measurement: SP2, Haze

Applicable process: Post gate etch clean

[H. Takahashi et al., ECS Transactions 2011 41(5), 163-170]
AOM (Ammonia/DIO₃ Mixture) for Ge Clean

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

[Screen Semiconductor Solutions Co., Ltd.]
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

Metal solution

Controlled contamination
Spin dry
Stored in FOUP
X days
Wet treatment

No clean
HF/HCl

Metal Contamination [atoms/cm²]

1.0E+14
1.0E+13
1.0E+12
1.0E+11
1.0E+10

1 day 3 days 35 days 1 day 3 days 7 days 35 days
No aging effect on MRE with HF/HCl even after 1 month

Screen Semiconductor Solutions Co., Ltd.

1 day 3 days 35 days 1 day 3 days 7 days 35 days
Under detection limit

Mn
Co
Zn
Ti
Cr
Fe
Ni
Summary for Surface Preparations on Ge

♦ **Recommended cleaning combination**
  - For particles: AOM (NH₄OH/DIO₃ mixture)
  - For metals: HF/HCl mixture
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Summary
One example: Ge corrosion during wet Ni removal using dHCl

GeO dissolves in aqueous solution

Anode:  
Ge + \( \frac{1}{2} O_2 \rightarrow GeO + e^- \)

Cathode:  
\( H^+ + e^- \rightarrow H_2 \)

\( O_2 + 2H_2O + 4e^- \rightarrow 4OH^- \)

Exposure of Ge & NiGe to the cleaning solution during Ge integration

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

<table>
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<tr>
<th>DO</th>
<th>8ppm</th>
<th>450ppb</th>
<th>25ppb</th>
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<tbody>
<tr>
<td>SEM image</td>
<td>Void</td>
<td>Void</td>
<td>No void</td>
</tr>
</tbody>
</table>

Void occurrence reduced


Void occurrence can be suppressed by the control of the oxygen concentration in liquid & ambient
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Summary
SiGe Wet Etches Selective to Ge

SiGe etch → HK/MG fill

Ge is too sensitive
- Conventional chemistries don’t work on this application

More study is needed on this kind of applications

SiGe/Ge loss in SC1

Etch Rate [nm/min] vs. SC1 conc. (NH4OH/H2O2/H2O=1/1/X)
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Summary
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-O₂ 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