SELECTIVE Ge REMOVAL FROM SiGe SURFACES FOR Si-CAP-FREE SiGe PASSIVATION

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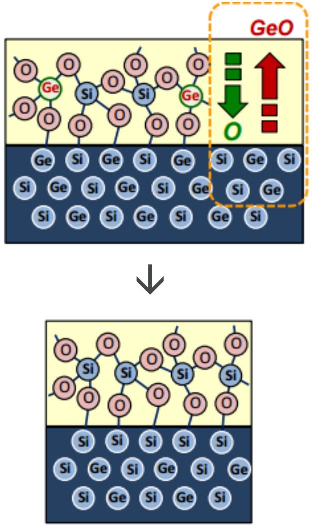
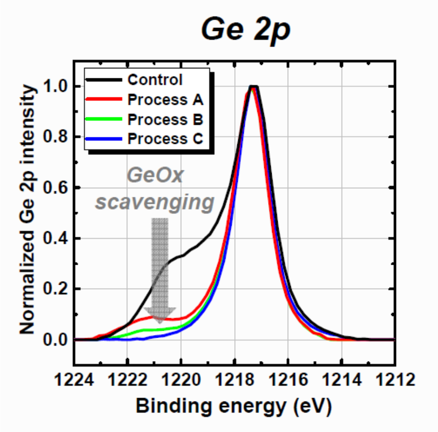
Si-CAP-FREE SiGe PASSIVATION

SiGe FIN OR GAA PASSIVATION IN RMG

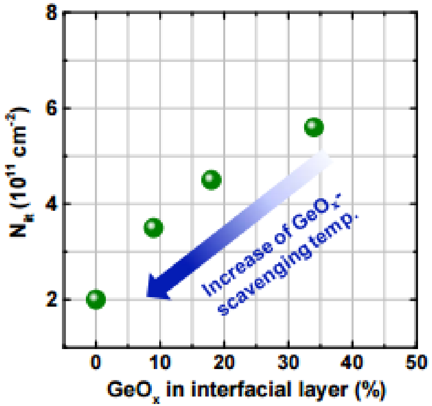
Ge-free oxide IL **and** interface enables SiGe passivation
= similar to Si cap without depositing Si-cap.





Process A, B and C:

- Removes GeO
- Variable efficiency in GeO_x removal



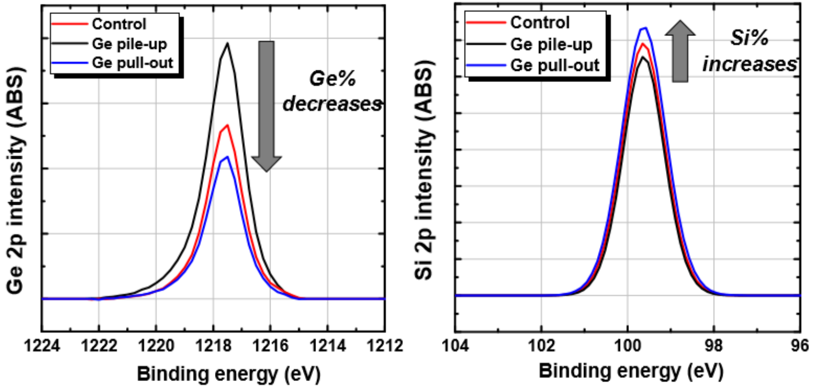
GeO_x scavenging reduces D_{IT}

[Lee et al. VLSI 2016 and Siddiqui et al. MRS Spring 2016]

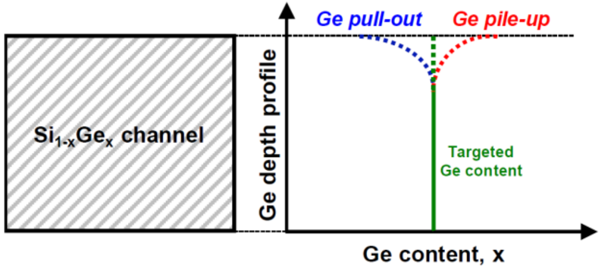
Si-CAP-FREE SiGe PASSIVATION

IMPACT OF SURFACE PREPARATION PRIOR TO IL GROWTH

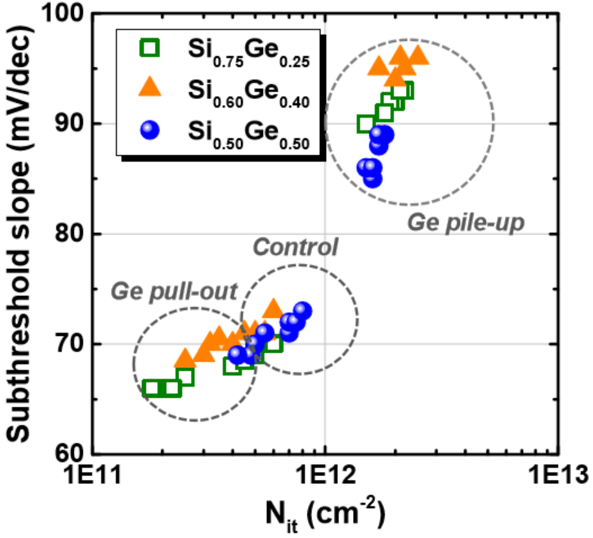
Ge conc at SiGe surface

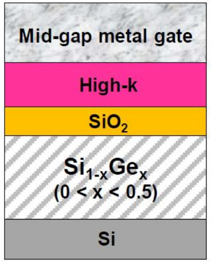


- Ge poor surface == Ge pull-out
- Ge rich surface == Ge pile-up



Electrical impact





(b)

Ge poor surface, i.e. Ge pull-out, results in best electrical performance. Unfortunately, no process information was shared.

[Lee et al. IEDM Tech Dig (2016) p. 766]

OUTLINE

- INTRODUCTION
- Ge PULL-OUT – SELECTIVE REMOVAL OF Ge FROM SIGE SURFACE
- IMPACT GE PULL-OUT ON Si-CAP-FREE SiGe PASSIVATION
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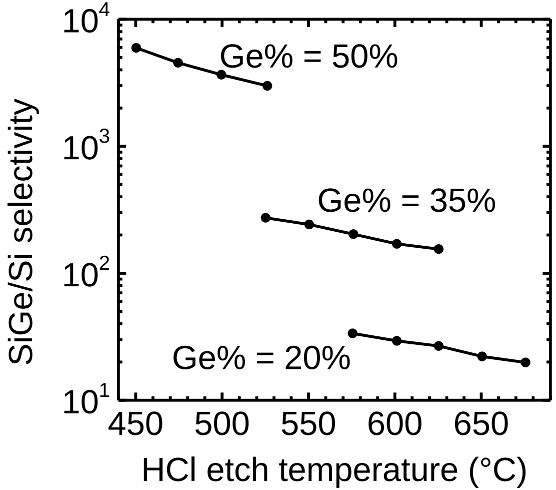
SELECTIVE Ge REMOVAL FROM SiGe SURFACE

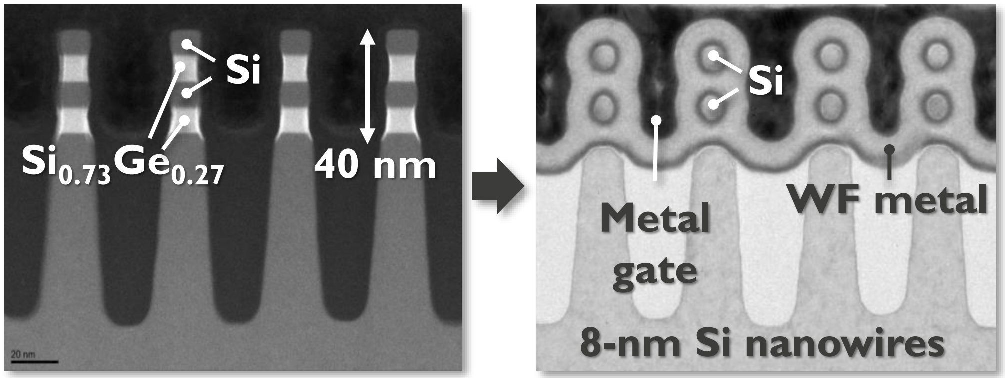
INSPIRED BY Si GAA SELECTIVE ETCH

HCl (G) SELECTIVE ETCH



[Destefanis et al., Semicond. Sci. Technol. 23, (2008) 105019]

Si GAA BY HCl (G)



[H. Mertens et al. VLSI Tech. Dig. (2016) p. 158]

- SiGe vs Si selective etch in HCl (g) enables Si GAA
- Selectivity attributed to enhanced $GeCl_2$ desorption compared to $SiCl_2$ in HCl (g) ambient.

→ Possible to use HCl (g) for surface preparation?

Ge PULL OUT – SELECTIVE Ge REMOVAL

NATIVE OXIDE COMPOSITION AFTER SURFACE TREATMENT

SiGe epi

|

HF (aq)

|

HCl (g)

|

Air exposure

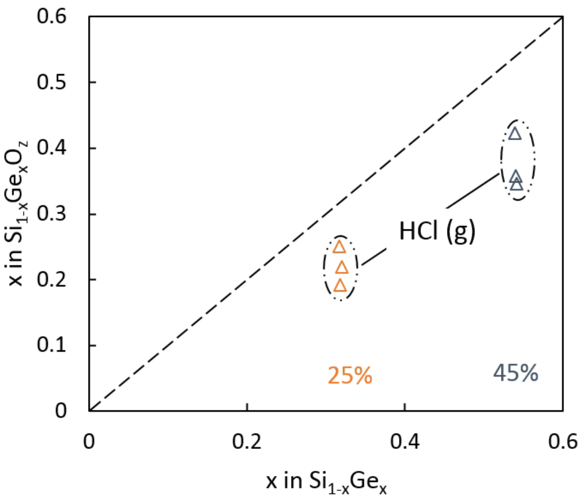
|

Native oxide

↓

Ge% from Ge3d and Si2p peaks

ANGLE-INTEGRATED XPS



- SiGe surface becomes Ge poor in HCl (g) ambient.

Ge PULL OUT – SELECTIVE Ge REMOVAL

NATIVE OXIDE COMPOSITION AFTER SURFACE TREATMENT

SiGe epi

|

HF (aq)

|

ASM Previum™

|

HCl or Cl_2 (g)

|

Air exposure

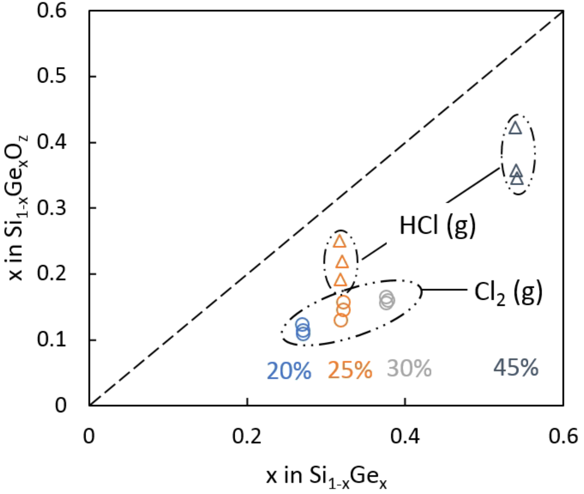
|

Native oxide

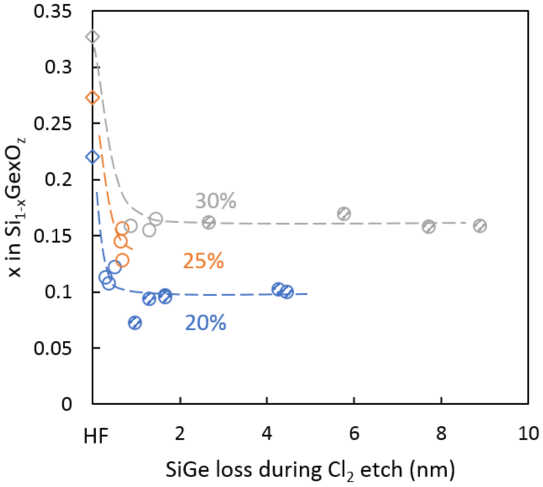
↓

Ge% from Ge3d and Si2p peaks

ANGLE-INTEGRATED XPS



IMPACT OF Cl_2 (g) TREATMENT TIME



- SiGe surface becomes Ge poor in HCl (g) and Cl_2 (g) ambient.
- Tuning process conditions allows for SiGe loss reduction while maintaining selective Ge removal → surface treatment.

Ge PULL OUT – SELECTIVE Ge REMOVAL

NATIVE OXIDE COMPOSITION AFTER SURFACE TREATMENT

SiGe epi

↓

HF (aq)

↓

ASM Previum™

↓

HCl or Cl_2 (g)

↓

Air exposure

↓

Native oxide

↓

Ge% from Ge3d and Si2p peaks

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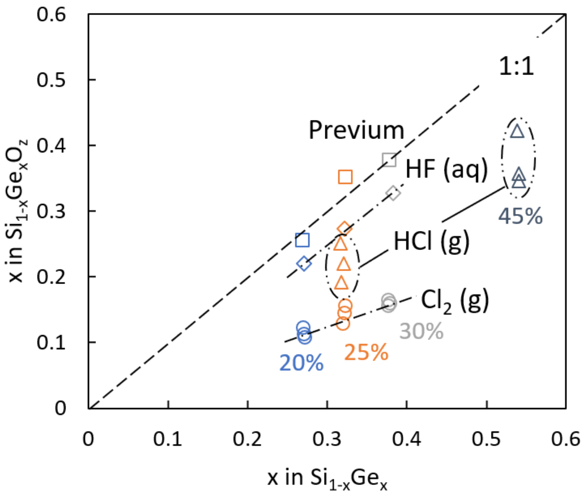
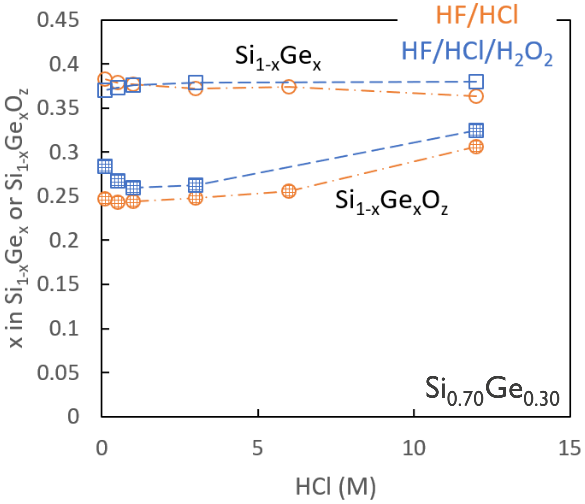


AQUEOUS HF SOLUTIONS



- SiGe surface becomes Ge poor in HCl (g) and Cl_2 (g) ambient.
- Tuning process conditions allows for SiGe loss reduction while maintaining selective Ge removal → surface treatment.
- Ge pull-out also observed in aqueous HF solutions. Ge pull-out efficiency depends on [HCl] and [H_2O_2], however never as efficient as Cl_2 (g).

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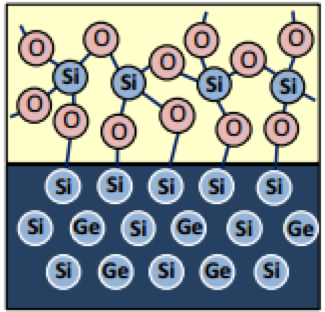
SiGe PASSIVATION – HOW TO? CHALLENGES.
Ge-OXIDE-FREE INTERLAYER

- Avoid Ge-oxide formation
  - Si cap – reference passivation method
  - Thermal interlayer – pure SiO_2 formed by Ge condensation
  - Ge pull-out prior to IL formation

- Ge-oxide scavenging
  - High solubility of GeO_2 in aqueous solutions
  - Scavenging prior to high-k deposition
  - Scavenging during post-metallization anneal (PMA)

} Imec POR

Ideal SiGe passivation



[Lee et al. VLSI 2016]

Oxide and interface composition:
- Pure SiO_2
- Interface contains only Si – O bonds
- No Ge gradient below interface

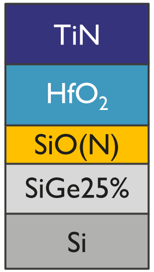
GeO SCAVENGING

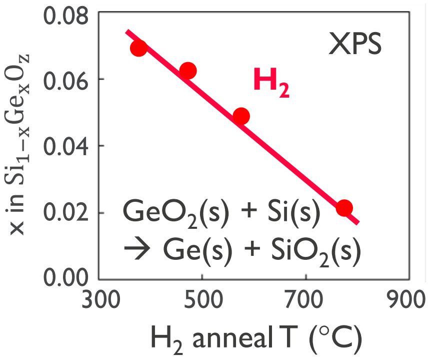
[H. Arimura et al. IEDM Tech Dig (2019) p. 667 and K. Wostyn et al. presented at ISTDM/ICSI 2019]

NH_3 ANNEAL + H_2 ANNEAL ON CHEMOX

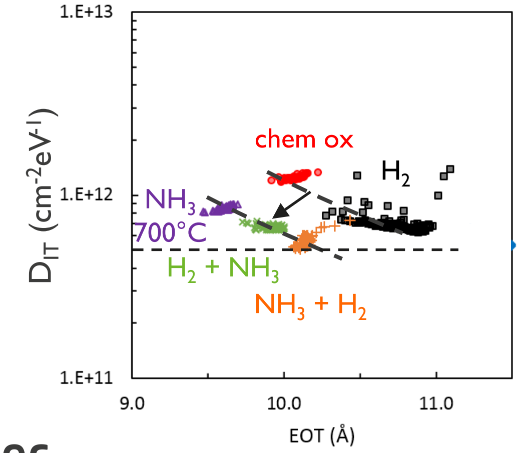
Limited delay

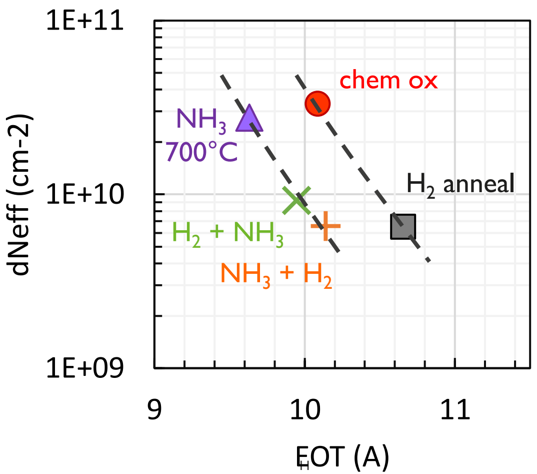
- SiGe 25-30% epi
- Chem ox.
- NH_3 anneal (700°C, 5 torr, 60 s)
- **H_2 anneal** (775°C, 40 torr, 2 min)
- Water rinse
- HfO_2 (2 nm)
- PVD TiN/W gate
- HPA: 400C, 20 ATM, H_2

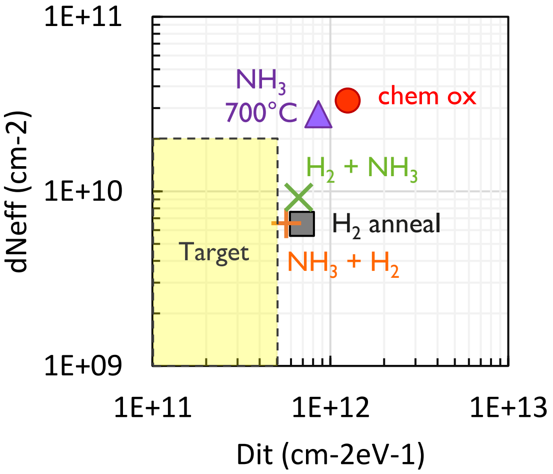




- H_2 anneal at high-T on SiO_2 (775°C, 40 torr, 2 min)
  - SiO vs GeO thermal stability difference
  - **GeO_2(s)** + Si(s) → Ge(s) + **SiO_2(s)**
- Additional NH_3 anneal on SiO_2 (700°C, 5 torr, 60 s)
  - Nitridation to suppress O / Vo diffusion and GeOx formation [J. Huang et al., APL 88, 143506 (2006).]
  - Increase in k-value (SiON)





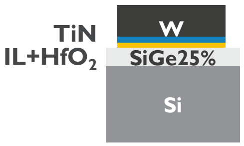


IMPACT OF GE PULL-OUT ON $Si_{0.75}Ge_{0.25}$ PASSIVATION

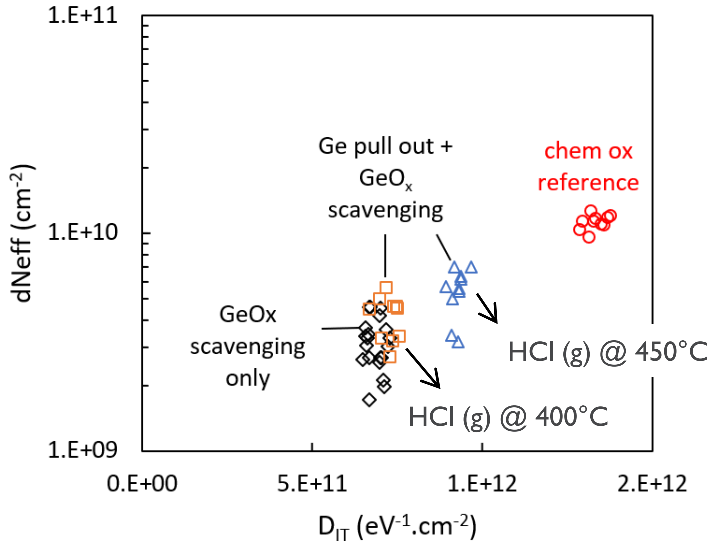
Ge PULL-OUT IN HCl (G) AMBIENT

SiGe passivation

- SiGe 25% epi
- HF 0.7% 60s
- **Ge pull-out: HCl (g)**
- O_3 (aq) chem ox
- GeO_x scavenging
- Water rinse
- HfO_2 deposition
- TiN/W gate
- Patterning
- HPA: 400C, 20 ATM, H_2



C-V hysteresis measurements at RT



- GeO_x scavenging improves SiGe passivation.
- Combining Ge oxide scavenging with Ge pull-out using HCl (g) shows no or small detrimental impact on dNeff vs Dit.

CONCLUSIONS

- Ge pull-out observed for SiGe < 50% in
  - Aqueous HF solutions, HCl (g) and Cl_2 (g) on oxide-free surface
  - Ge pull-out most efficient using Cl_2 (g)
- Si-cap-free SiGe passivation
  - Improved SiGe passivation by combining chem oxide with Ge-oxide scavenging
  - No or small detrimental impact observed when Ge pull-out in HCl (g) combined with Ge-oxide scavenging
- Future: impact of Ge pull-out on SiGe oxidation → come and see at UCPSS!

embracing a better life

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|

HF (aq)

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ASM Previum™

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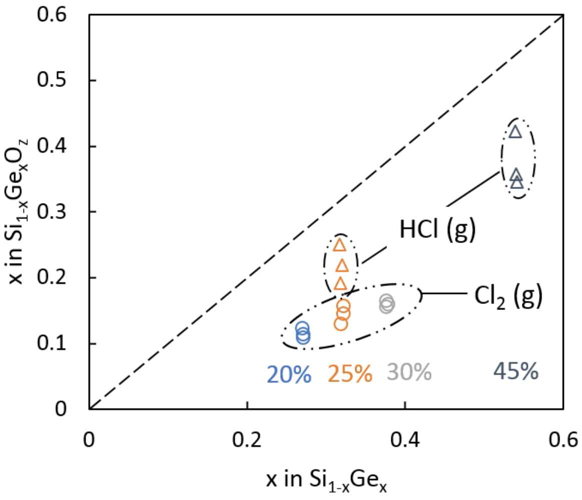
HCl or Cl_2 (g)

↓

Air exposure

Native oxide

ANGLE-INTEGRATED XPS



DESORPTION OF HCL (ADS) ON GE (100)

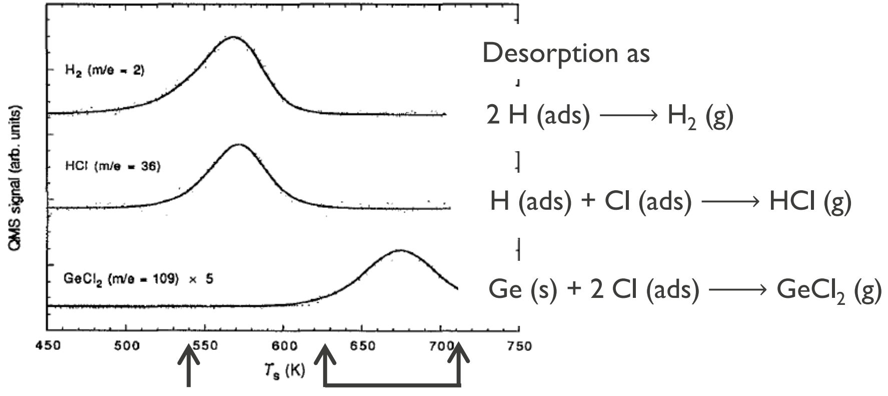


FIG. 1. TPD spectru Cl_2 rption products HCl)0) following a saturation dose of HCl. For $GeCl_2$ the $GeCl^+$ cracking fraction was actually detected.

[D'Evelyn et al. J. Chem. Phys. 101 (1994) 2463]

Difference in surface Ge conc between HCl and Cl_2 possibly (partially) related to difference in T during surface preparation step.