DUMMY POLY GATE ETCH RESIDUE REMOVAL

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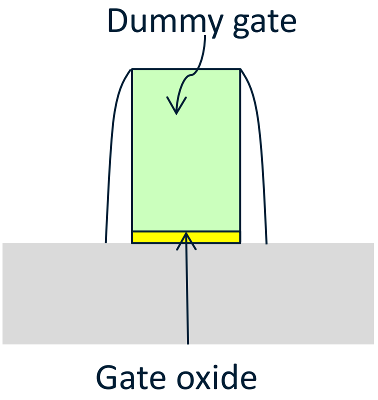
Outline



1. **Background introduction**
   - Technical challenge of conventional Si etchant
   - Anisotropic Si wet etching
2. **Design concept of novel Si etchant**
   - Etch rate requirement
   - Formulation design
   - Experimental trails
   - Computation modeling
   - Application in FEOL process
3. **Summary**

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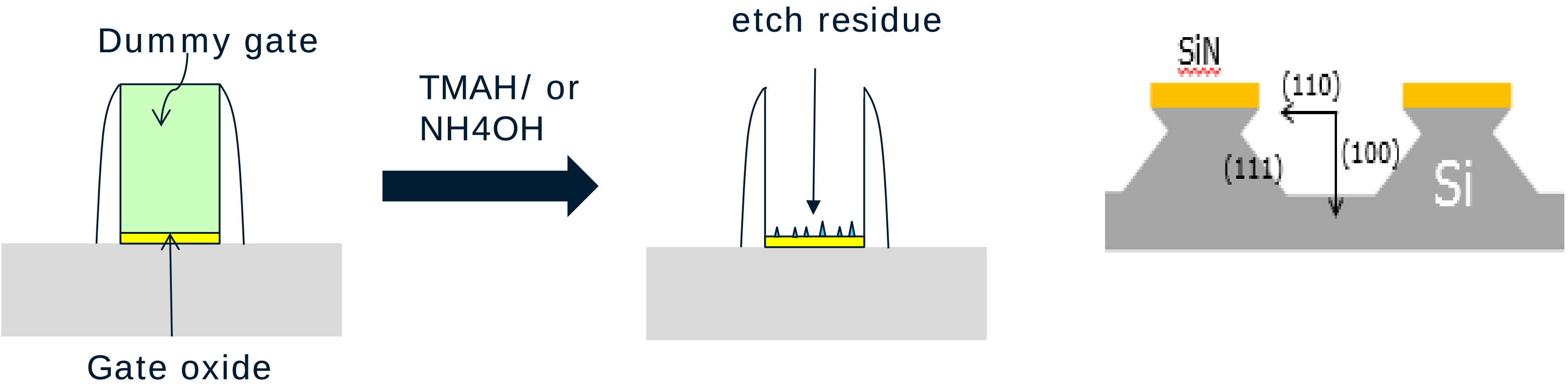
Technical challenge of conventional Si etchant

➢ Issue of conventional Si wet etchant

Due to the anisotropic etch characteristic, the pyramid shape etch residues will be generated for conventional Si etchant.



We need high Si etching power in Si(110) and (111) orientations.

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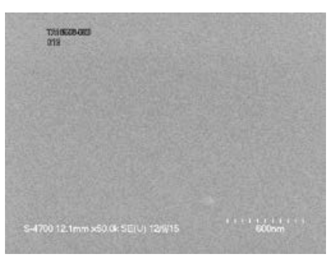
Anisotropic Si wet etching

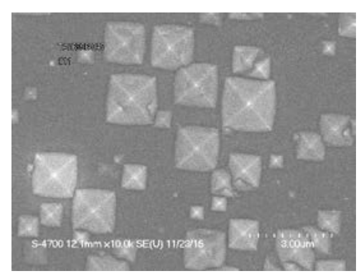
Etch rate of conventional Si wet etchant

	Etch rate (A / min)			Selectivity	
	Si (100)	Si (110)	Si (111)	Si(110) / Si(100)	Si(111) / Si(100)
conventional etchant 1	7117	2228	98	0.31	0.01
conventional etchant 2	4256	2075	870	0.49	0.20

For conventional Si wet etchant, the etch rate in Si(100) direction is much higher than in (111) which results in pyramid shape etching profile.

Bare Si (100) → Conventional Si etchant





(Top view SEM)

pyramid shape etching profile

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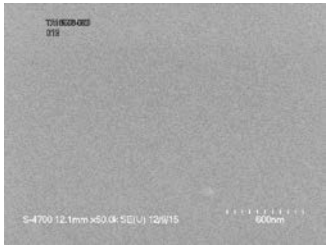
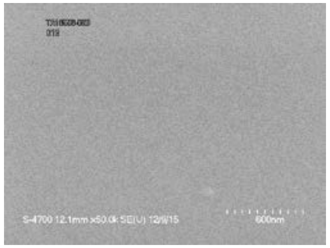
Etch rate requirements

To address the etch residue issue, etch rate in Si (111) and Si (110) directions should be increased.

	Etch rate (A / min)						Selectivity	
	Si (100)	Si (110)	Si (111)	a-Si	Poly Si	ALD oxide	Si(110) / Si(100)	Si(111) / Si(100)
Target	>1000	>1000	>500	>300	>600	<0.1	>1	>0.5

Bare Si (100) → New Si etchant





(Top view SEM)

No pyramid shape etching profile

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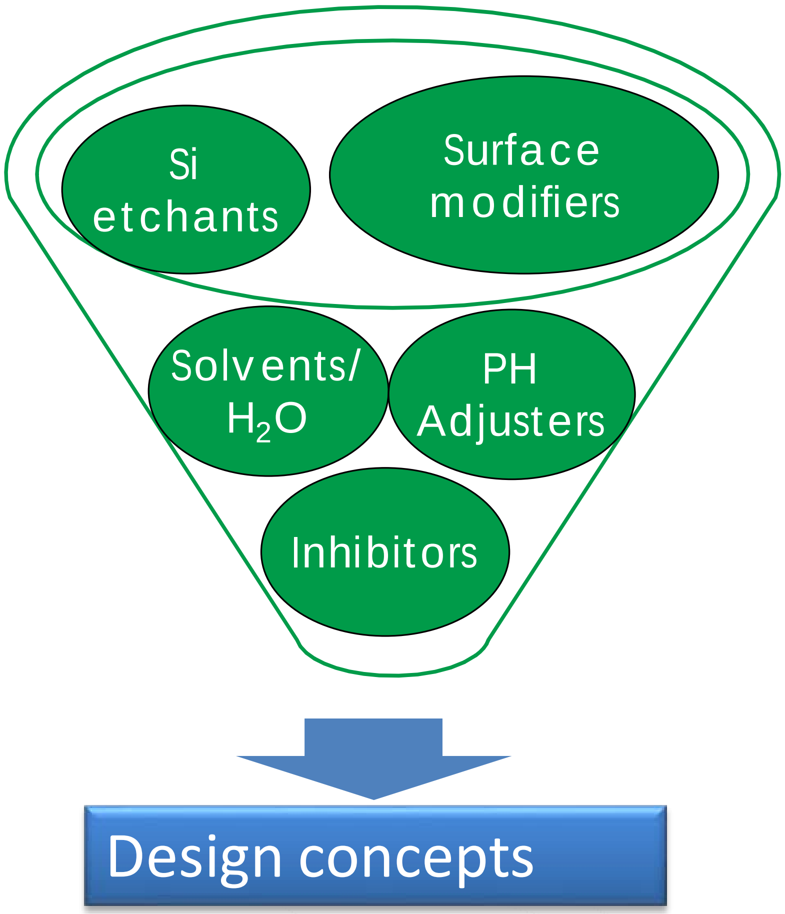
Formulation design



Etchants:
Dissolves Mono-crystalline Si

Surface modifiers:
Suppress the anisotropic Si etching;
improve the wettability

Solvents/H_2O:
Removes organic/inorganic residues
Vary the viscosity of formulations

PH adjusters:
maintains pHs

Inhibitors:
Preserve SiOx, barrier liner and Cu

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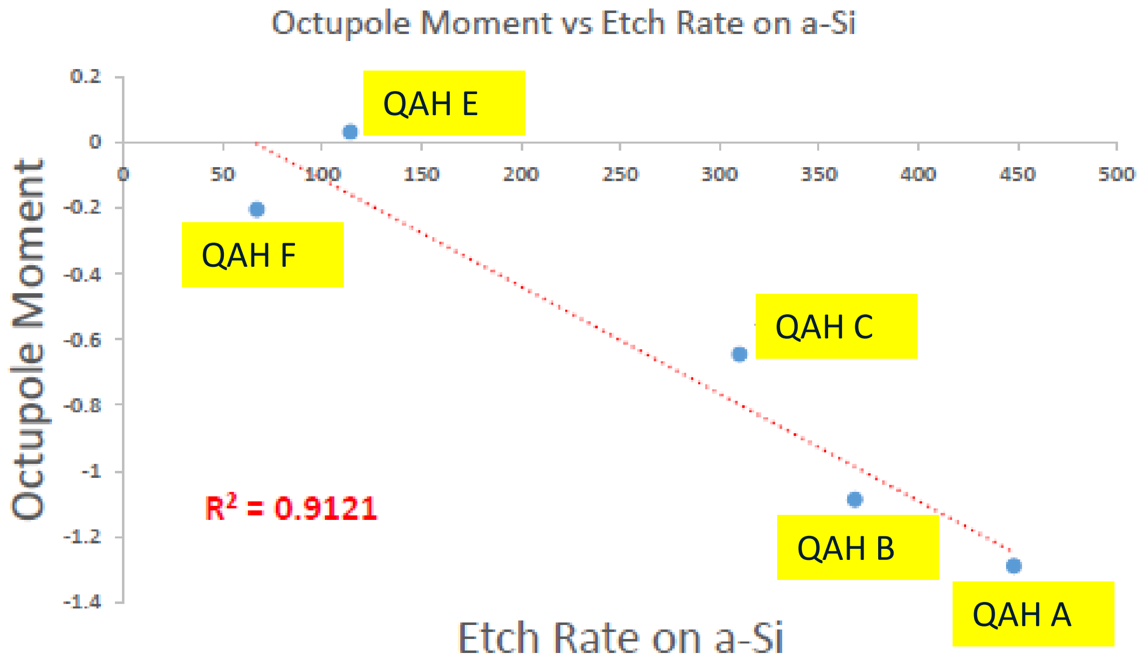
Computational modeling

➢ Impact of different quaternary ammonium hydroxide (QAH) in a-Si etch rate



- Strong correlation between cation-only electrostatic octupole moment and experimental a-Si etch rate
- Etch rate increases with greater electrostatic octupole moment magnitude
- This result suggests that the charge distribution of our cation is playing a key role in the observed etch rate

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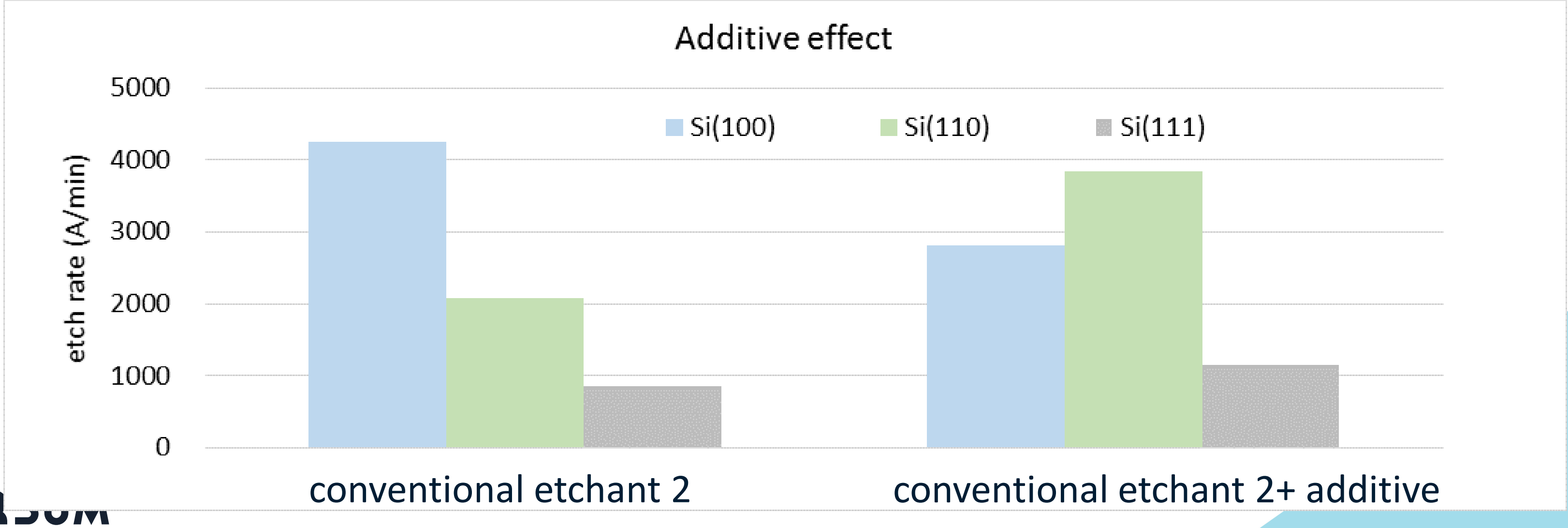
Additive effect in Si etching selectivity

- An effective additive increases Si (110), (111) etch rates and maintains Si (100) etch rate at high level.

	Etch rate (A / min)			Selectivity	
	Si (100)	Si (110)	Si (111)	Si(110) / Si(100)	Si(111) / Si(100)
conventional etchant 2	4256	2075	870	0.49	0.20
conventional etchant 2 + additive	2821	3845	1155	1.36	0.41



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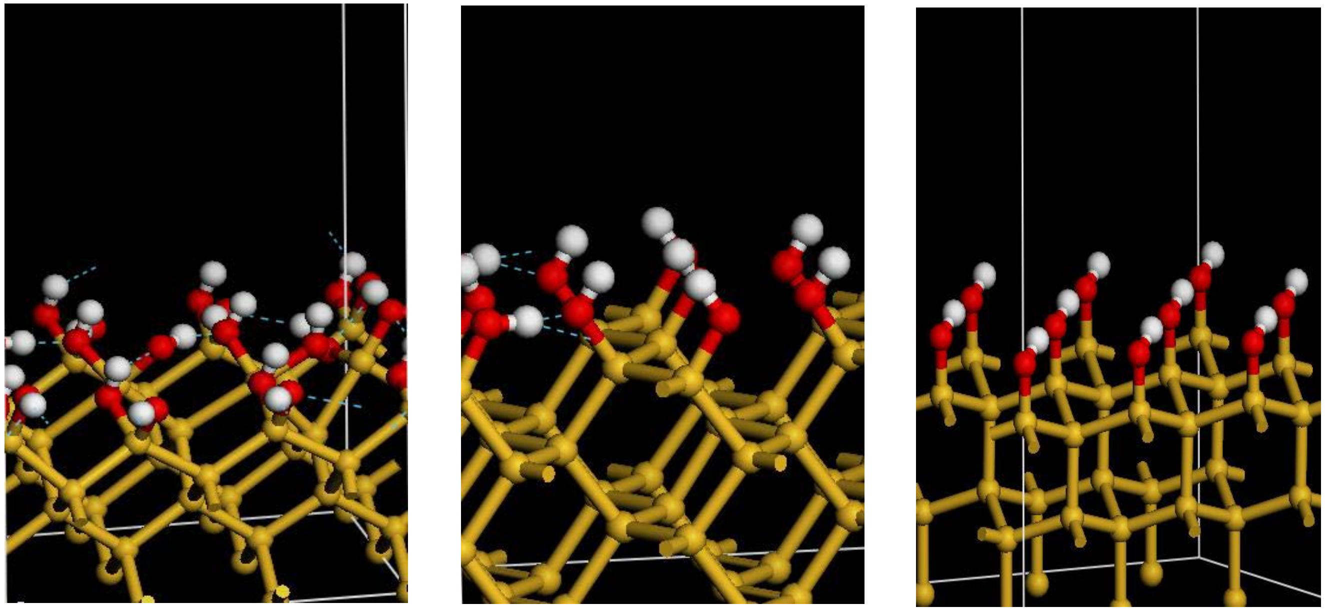
Computational modeling

➢ Si surface

Si (100) | Si (110) | Si (111)



- Both Si (111) and Si (110) surfaces are Si(OH) terminated while the Si (100) surface is $Si(OH)_2$ terminated.
- The Si (110) surface has step sites (greater overall surface roughness).
- All surfaces showed some degree of H-bonding on surface with the greatest amount seen for the Si (100) surface.

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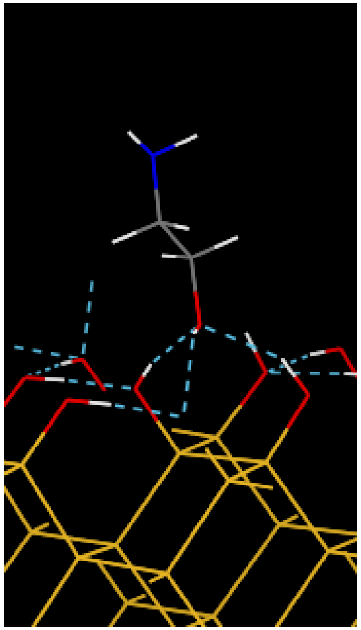
Computational modeling

Effect of surface symmetries on additive binding

Average additive binding energies (kcal / mol)		
Si (110)	Si (100)	Si (111)
-4.4	-1.0	-1.8



- All binding energies were negative and favorable on each of the surfaces.
- Highest surface coverage of additive is on Si (110) surface.

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Our thoughts

- Si (110) : Si (100) : Si (111) surfaces have ratio of 4:1:2 additive surface coverages
  - Surface with greatest e/r in presence of additive also has the greatest surface coverage of additive which is consistent with experiments

- Previously, rate-determining step (RDS) for Si etching process in a basic environment was found to be the formation of the surface $–Si(OH)_3$group
  - additive which was found to interact strongly with surface OH groups can aid in reorganizing the active site to lower RDS activation barrier and increase e/r

- Also, once $Si(OH)_4$ is generated, additive has a ~-16 kcal/mol favorable interaction energy with it
  - additive can help to keep $Si(OH)_4$ from crashing out of solution because of high water solubility of additive

- Si (100) surface may undergo unfavorable water elimination at surface in the presence of additive, which is consistent with experiments showing a decrease in e/r in the presence of additive

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Experimental trails

	Etch rate (A/min)						Selectivity	
	Si (100)	Si (110)	Si (111)	a-Si	Poly Si	ALD oxide	Si(110)/ Si(100)	Si(111)/ Si(100)
Target	>1000	>1000	>500	>300	>600	<0.1	>1	>0.5
conventional etchant 1	7117	2228	98	n.a	n.a	n.a	0.31	0.01
conventional etchant 2	4256	2075	870	n.a	n.a	n.a	0.49	0.20
Versum Material's new etchant	2674	3821	1561	586	1753	0.08	1.43	0.58

Note: All the etch rate were measured at 50C. Unit: A/min

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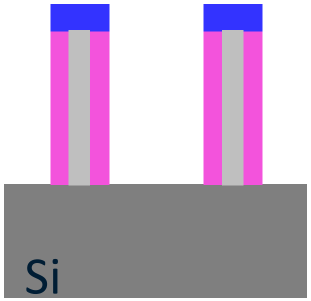
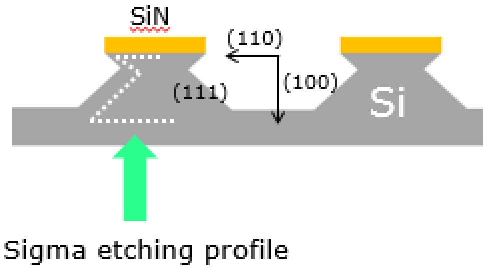
Application in FEOL process

➢ **Sigma shape generation for S/D**

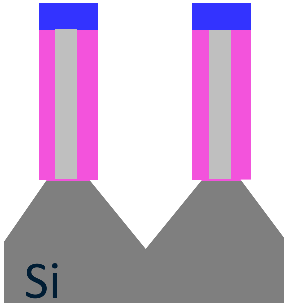
before etching





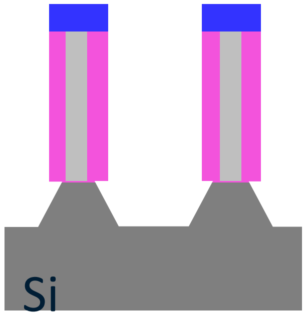
after etching

Conventional



V shape

Target



Flat bottom

Sigma shape generation by wet etching process is achievable by Versum's novel Si etchant.

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Summary

For the studies of Versum Material's novel Si etchant, we demonstrate the following achievements:

- ✓ excellent dummy poly gate etch residue removal capability.
- ✓ etching selectivity of Si (110)/ (100) and Si (111)/ (100) reaches 1.5 and 0.5 respectively.
- ✓ compatible with HK, oxide, SiN and SiGe
- ✓ could be operated as recirculation mode, bath-life over 72hrs at 50C.
- ✓ applicable on single wafer tool

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