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Renewed interest in cryogenic etching processes: what are the advantages of cooling the substrate?

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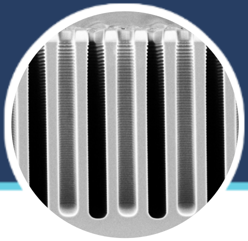
***G**roupe de **R**echerches sur l'**E**nergétique des **M**ilieux **I**onisés*
14 rue d'Issoudun 45067 Orléans Cedex 2 France



Outline

✓ Introduction, history and principle of cryoetching

✓ Deep Cryo-Etching of Silicon

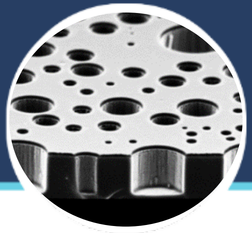
✓ Passivation layer formation by SiF_4/O_2 plasma

✓ Passivation steps using CF_4 plasma instead of C_4F_8

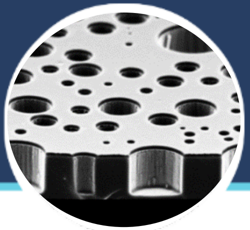
✓ Cryo Atomic Layer Etching

✓ What makes cryogenic etching popular again in the industry ?

✓ What are the advantages of cooling the substrate ?



Introduction, principle and history of cryo-etching of Silicon



Introduction to cryochemistry

- It is counterintuitive that **chemical reactions can be accelerated at low temperature**, by freezing. [1]
- However, this phenomenon has been highlighted by the "cryo-chemistry" community since the 50ies.[2]

Example [3]: in the following reaction,

$$aA + bB \rightarrow \text{products}$$

The reaction rate is given by :

$$\text{Rate} = k'[A]^a[B]^b$$

k' is the rate coefficient and follows an Arrhenius law

$$k' = A' \exp(-E_a/RT)$$

A' = Arrhenius pre-exponential factor
E_a : activation energy

By decreasing T, k' should decrease as well.
A' (frequency factor) should also decrease as T decreases

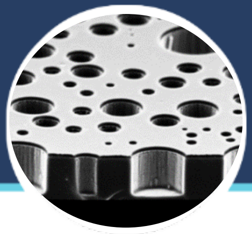
⇨ The rate should decrease…

BUT…

[1] 2021: An, L.-Y. et al. Advances in Cryochemistry: Mechanisms, Reactions and Applications. Molecules 26 750

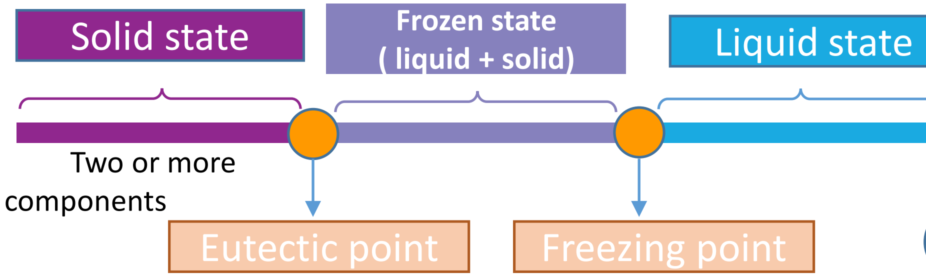
[2] 1962: H. A. McGee and W. J .Martin Cryochemistry, Cryogenics, vol2 (5) 257

[3] 2023: Jiaxin Lv et al. Freeze-accelerated reactions on environmental relevant processes Cell reports Physical Science 4 101456

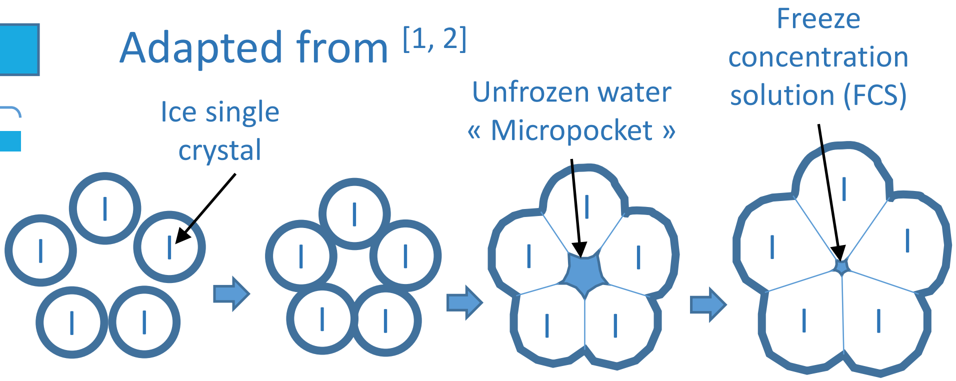


Introduction to cryochemistry (cont'd)

- Example in a frozen solution or impure solid, there is a gradual transition from solid to liquid



Adapted from [1, 2]



- Freezing begins when T is below the freezing point

- In the frozen state, the substance is in equilibrium between its solid and liquid phases.

- Unfrozen regions behave as « micropockets » and provide special microenvironments for chemical reactions.

- If all solutes are rejected from ice crystals to the unfrozen solution, the concentrations of solutes A and B in the micropockets, $[A]_{mp}$ and $[B]_{mp}$ can be expressed as:

$[A]_{mp} = [A]\, C_{mp} / C_T$ $[B]_{mp} = [B]\, C_{mp} / C_T$ $Rate = k'[A]_{mp}^{a}[B]_{mp}^{b}$

- ⇨ Concentration effect which accelerates the reaction

[1] 1996: Norimichi Takenaka et al. Acceleration Mechanism of Chemical Reaction by Freezing J. Phys. Chem., Vol. 100, No. 32

[2] 2023: Jiaxin Lv et al. Freeze-accelerated reactions on environmental relevant processes Cell reports Physical Science 4 101456

Brief history of the cryogenic etching process

Tachi’s team proposed to cool the substrate down to a temperature between **-100** and **-130°C** while running a **microwave SF_6 plasma** to etch silicon anisotropically.

1988 : S. Tachi *et Al.* Appl. Phys. Lett., 52(8), 616(1988)

The idea was to **freeze chemical reactions** on vertical sidewalls of the sample and favor ion-assisted reactions at the feature bottom.

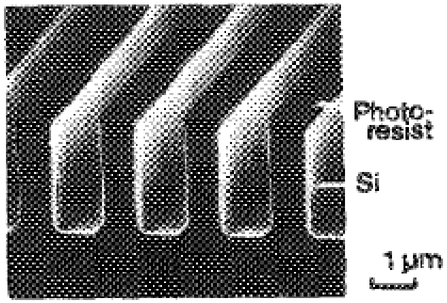
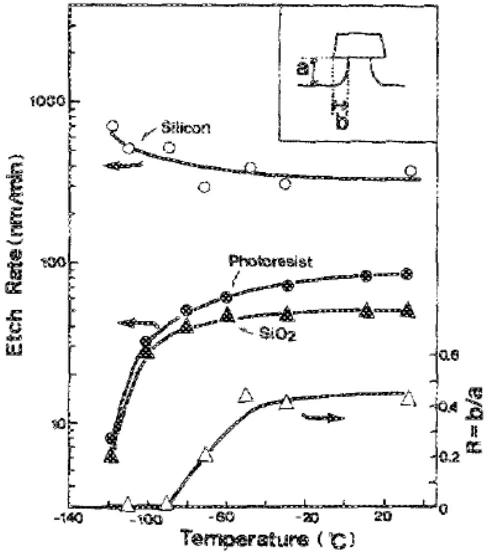
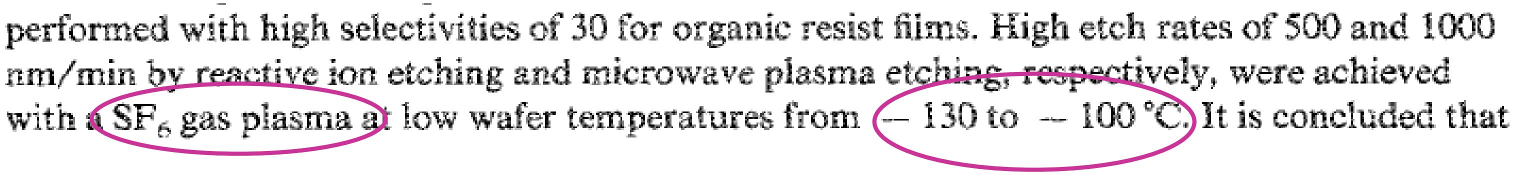


FIG. 3. Silicon profile etched at
with the use of SF_6 gas plasma.

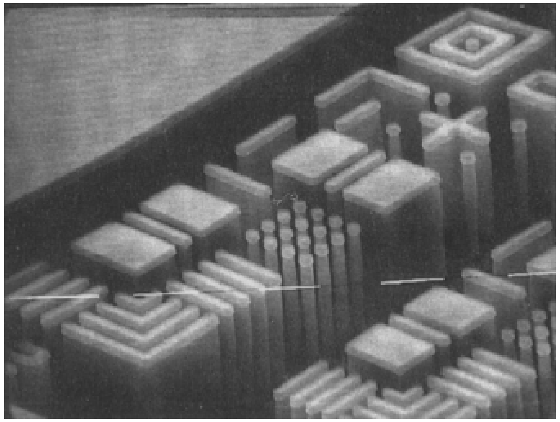


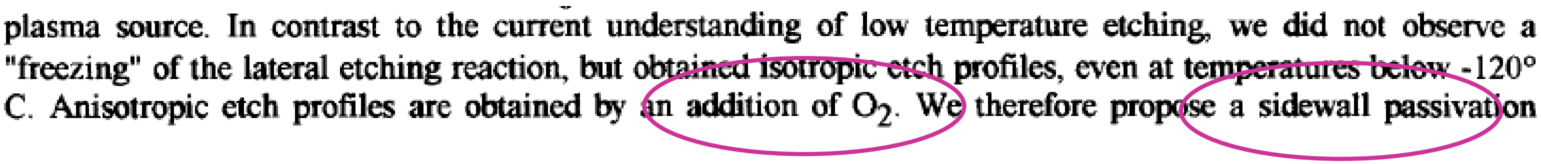


performed with high selectivities of 30 for organic resist films. High etch rates of 500 and 1000 nm/min by reactive ion etching and microwave plasma etching, respectively, were achieved with a SF_6 gas plasma at low wafer temperatures from − 130 to − 100 °C. It is concluded that

Brief history of the cryogenic process (cont'd)

- 1995 : J. W. Bartha et Al. Microelectron. J., 43, 453(1995)





plasma source. In contrast to the current understanding of low temperature etching, we did not observe a "freezing" of the lateral etching reaction, but obtained isotropic etch profiles, even at temperatures below -120° C. Anisotropic etch profiles are obtained by an addition of O_2. We therefore propose a sidewall passivation

For the first time, a mechanism based on sidewall passivation was suggested in cryogenic etching instead of a mechanism based on a low reaction probability of the radicals on very cold silicon surfaces.

Principle of cryoetching of Silicon

SF_6/O_2 plasma

✓<u>Chemical etching</u> (selective)

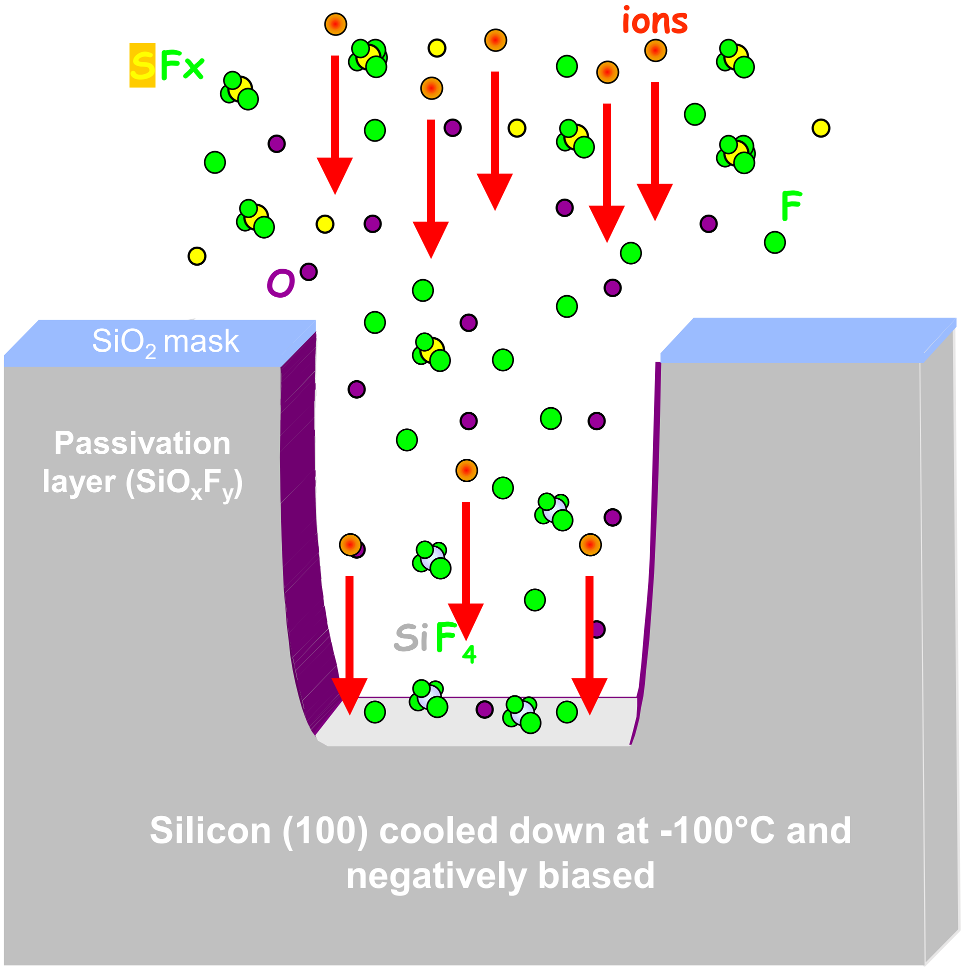
SiF_4 : main etching product

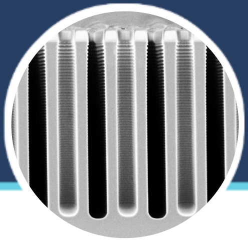
✓ <u>Passivation layer (</u>SiO_xF_y)

Only forms at very low temperature

✓ Fragile passivation layer, easily removed by ion bombardment

Simultaneous mechanisms





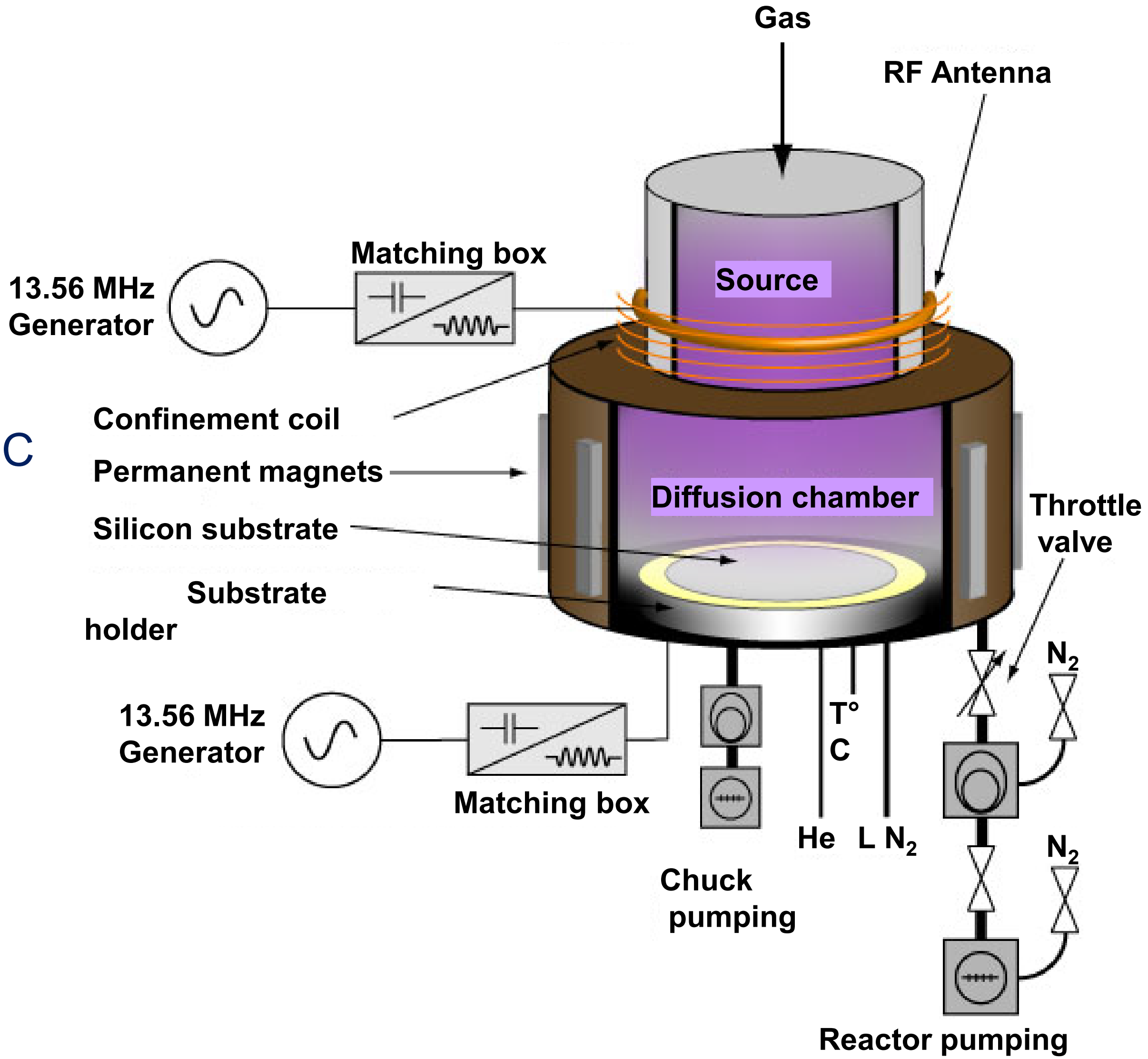
Typical reactor used for cryoetching

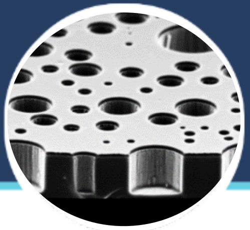
Parameter range:

Pressure : 3 – 10 Pa
Power : 500 – 3000 W
Bias : 0 – 100V
SF_6 : 50 – 1000 sccm
SiF_4 : 0 – 100 sccm
O_2 : 0 – 70 sccm
Temperature : -150°C → 20°C

Diagnostics:

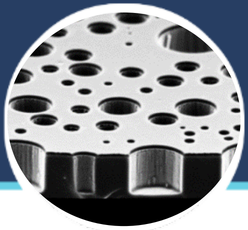
In-situ ellipsometry
Mass spectrometry





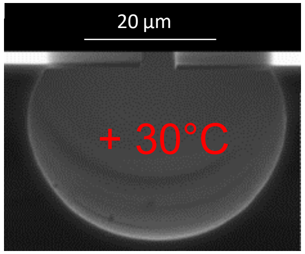
Deep Cryo-Etching of Silicon

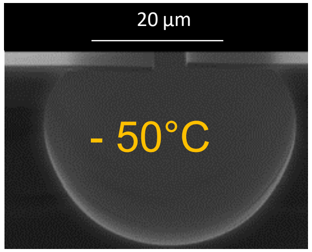
Passivation layer characterization in SF_6/O_2 plasma

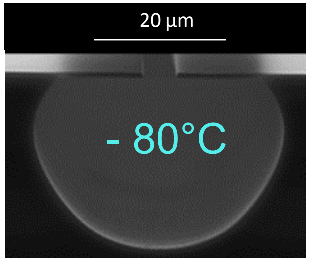


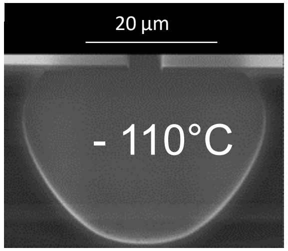
Role of oxygen, temperature and ion bombardment

SF$_6$ plasma without bias









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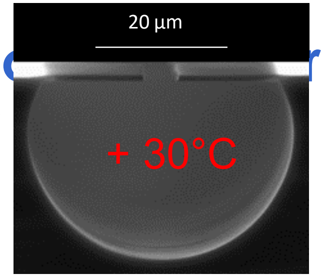
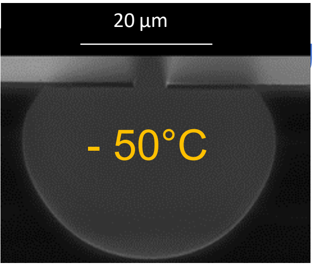
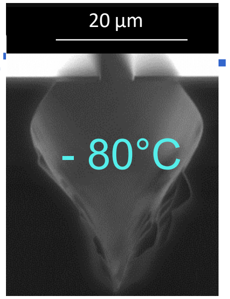
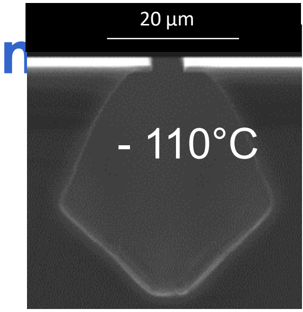
SF$_6$/O$_2$ plasma without bias





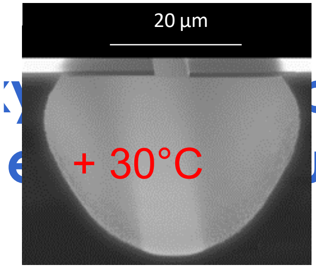


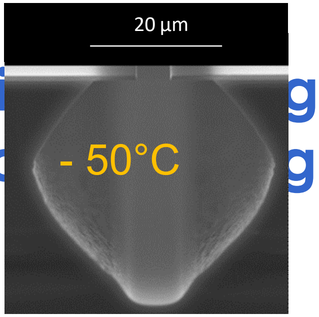


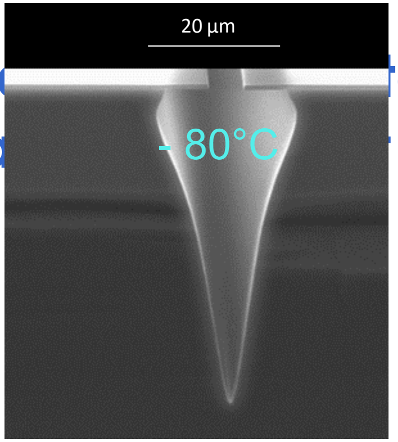
With ox profi ge te

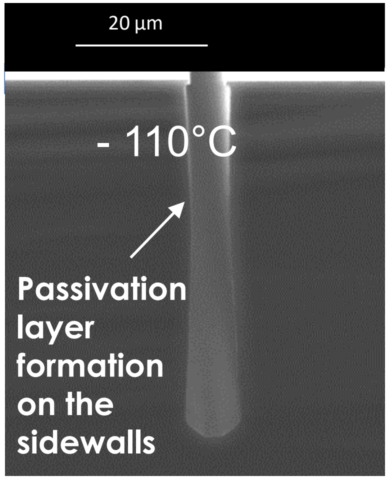
Lozeng e ue to gra -

SF$_6$/O$_2$ plasma with bias



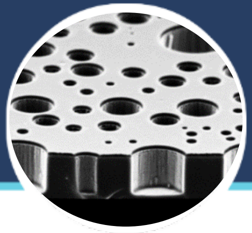






Passivation layer formation on the sidewalls

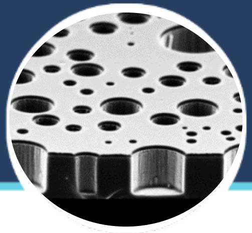
Anisotropic etching at -110°C with oxygen and bias



⇨ What is the **composition of the passivation layer** ? What is the **role of the etched by-products** ?

⇨ What are the **main mechanisms involved in the formation of the passivation layer** ?
Why is it necessary to cool the substrate ?

⇨ How to enhance the **robustness of the passivation layer** in the cryogenic process ?



Ex-Situ XPS analysis

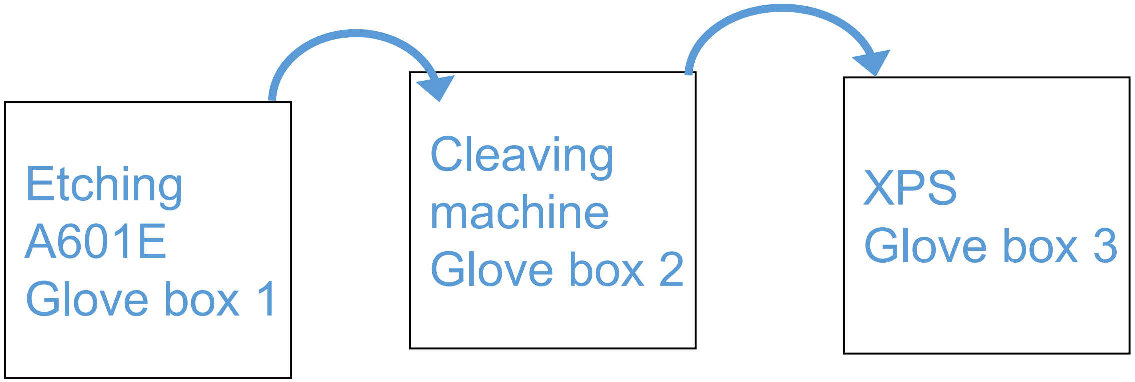
Objective of this experiment : analyze the passivation layer after etching, but without leaving the sample being oxidized by the ambient air.

Method :

1. After etching, the sample is removed from the reactor in the glove box 1 full of pure N_2 gas

2. Transportation of the wafer (under pure N_2) toward the glove box 2 where cleavage is performed. (Residual O_2 rate controlled <0.1 %).

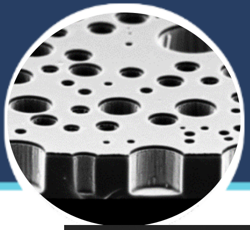
3. After cleavage, transportation of the trench to be analyzed in another lab in a 3rd glove box for XPS.



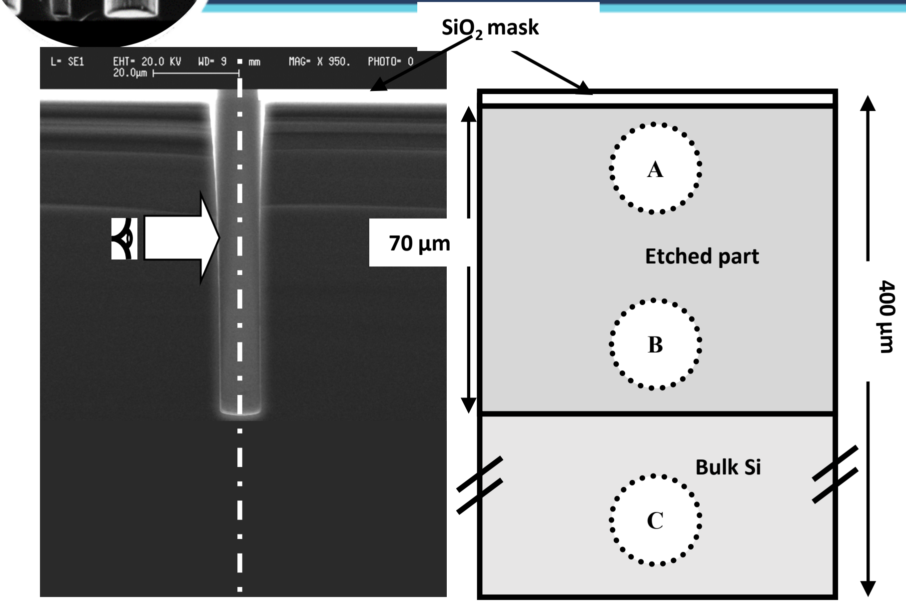
Etching
A601E
Glove box 1

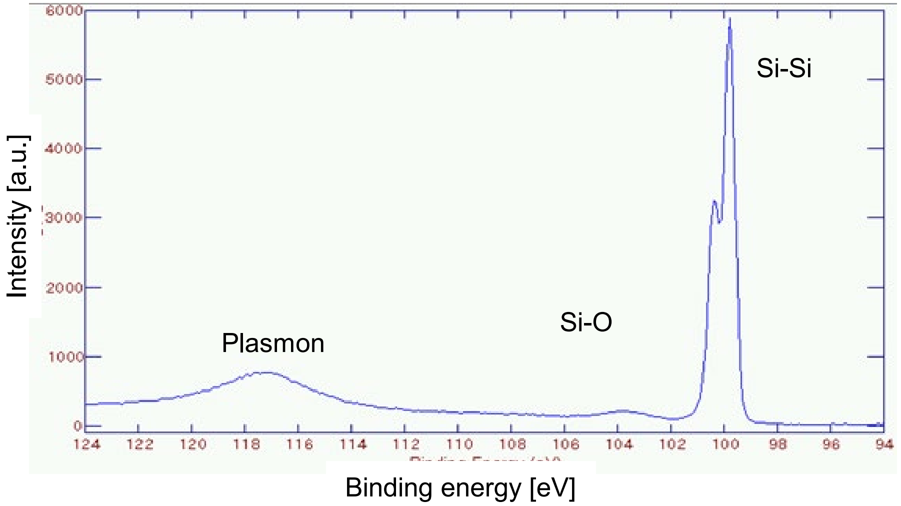
Cleaving
machine
Glove box 2

XPS
Glove box 3



Ex-Situ XPS analysis (cont'd)





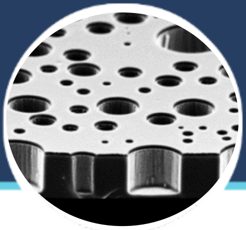
Lines	Peak Center [eV]	Ratio (±0.01)		
		A	B	C
F /Si-Si	F 1s- 688	0.02	0.02	0.01
O / Si-Si	O 1s–533.5	0.13	0.15	0.14
C / Si-Si	C 1s– 285.3	0.11	0.15	0.11
Si-O / Si-Si	Si 2p−103.7	0.03	0.03	0.03

✓ Nearly no oxidation (SiO$_2$) on the passivated surfaces.

✓ Low contamination

⇨ The passivation layer **is removed when** the wafer is warmed back up to ambient temperature

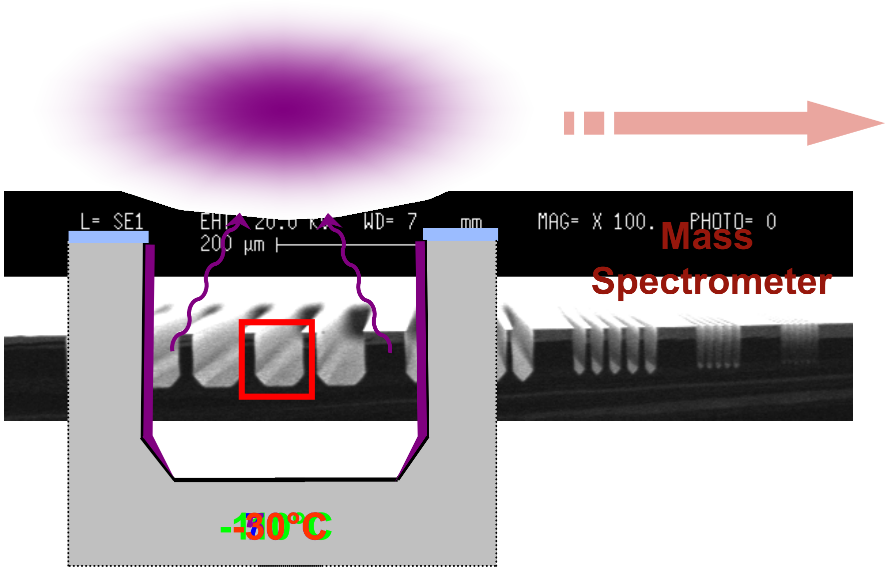
(1)R. Dussart *et al* J. Micromech. Microeng., 14, 190-196 (2004)



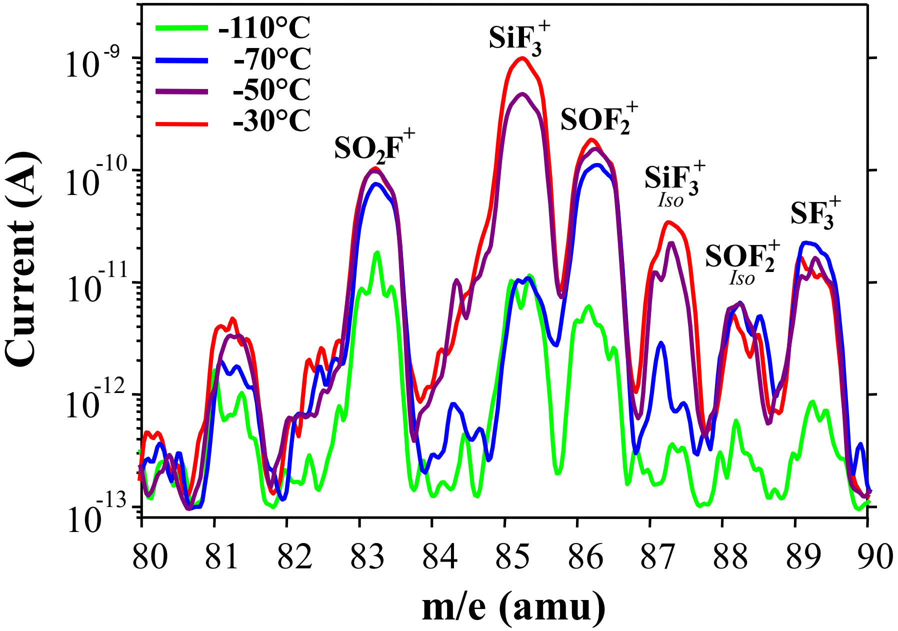
Desorbed species - Mass spectrometry analysis

Passivation layer characterization by mass spectrometry

analyze the desorbed species coming from trench sidewalls when the wafer is warmed back to ambient temperature.



Heating (from -110°C to -30°C)



SO_xF_y (SO_2F^+, SOF_2^+) desorption from -110°C to -70°C

SF_x (SF_3^+) desorption between -110°C and -70°C

SiF_4 (SiF_3^+) desorption between -70°C and -30°C

✓ SiF_4 forms during the sample warming

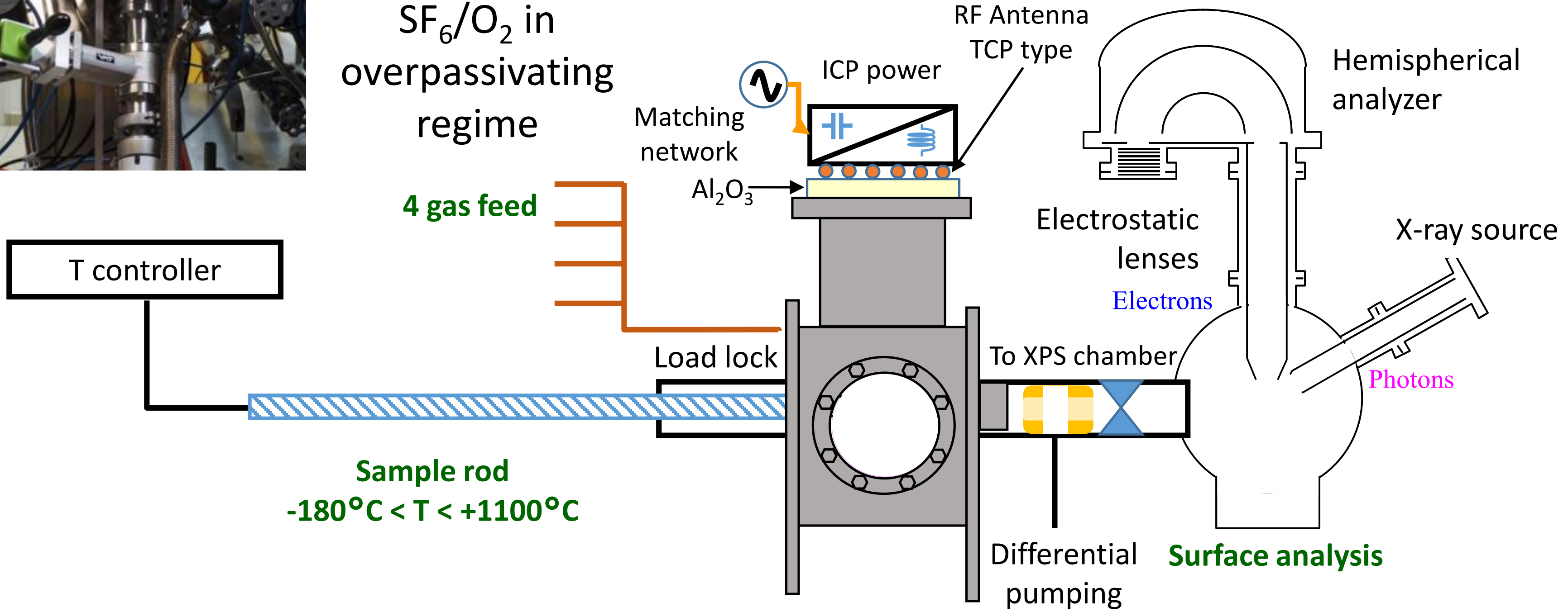
X. Mellhaoui et al., J. Appl. Phys., 98, 104901 (2005)

In-situ X-Ray Photoelectron Spectroscopy

OPTIMIST Platform (IMN, Nantes)

Christophe Cardinaud, Aurélie Girard

SF_6/O_2 in overpassivating regime



RF Antenna TCP type

ICP power

Hemispherical analyzer

Matching network

Al_2O_3

4 gas feed

Electrostatic lenses

Electrons

X-ray source

T controller

Load lock

To XPS chamber

Photons

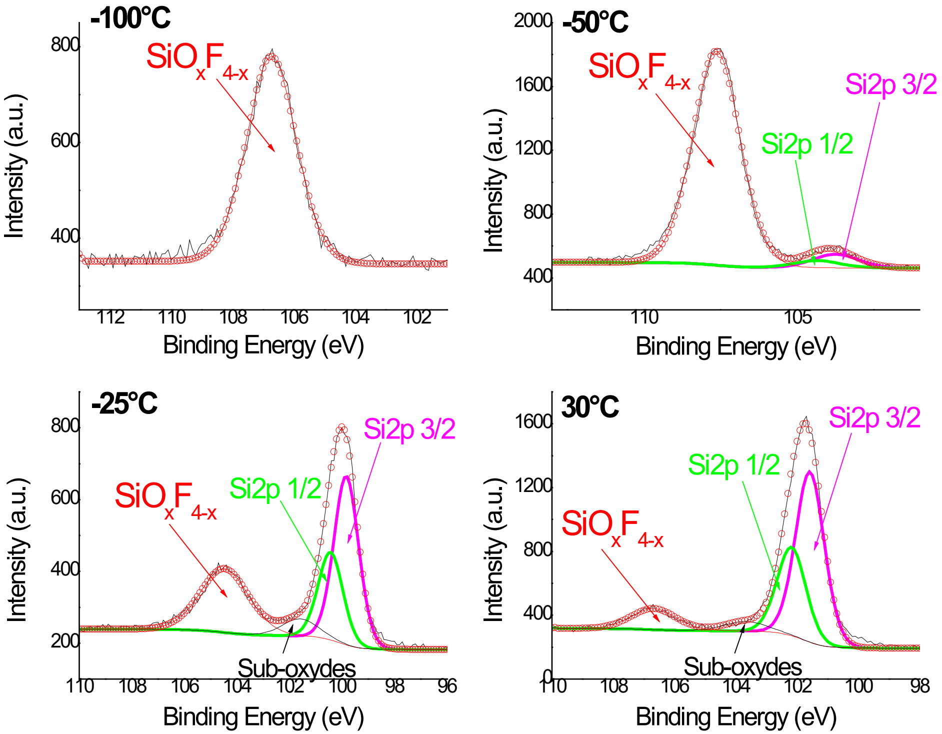
Sample rod

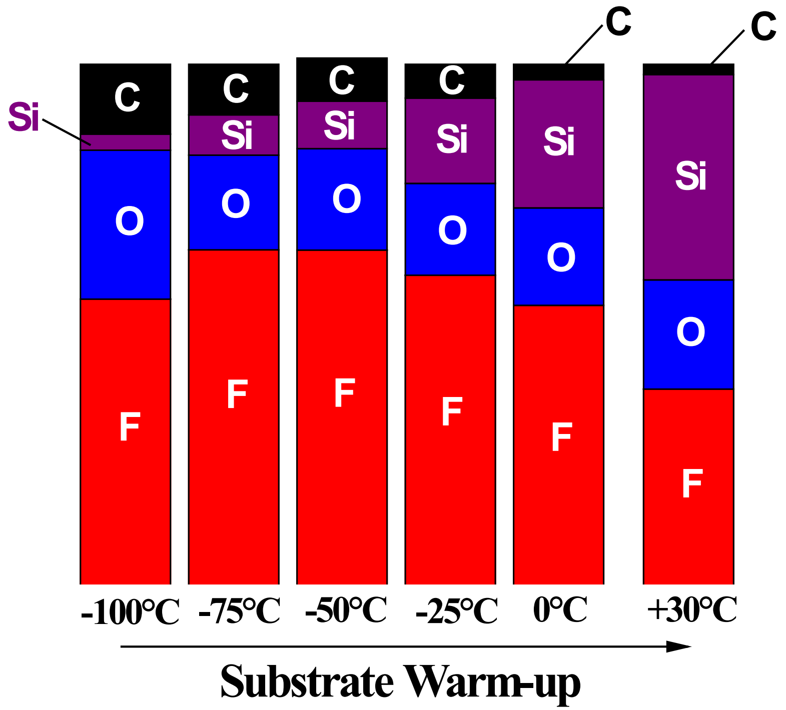
-180°C < T < +1100°C

Differential pumping

Surface analysis

In-situ X-Ray Photoelectron Spectroscopy

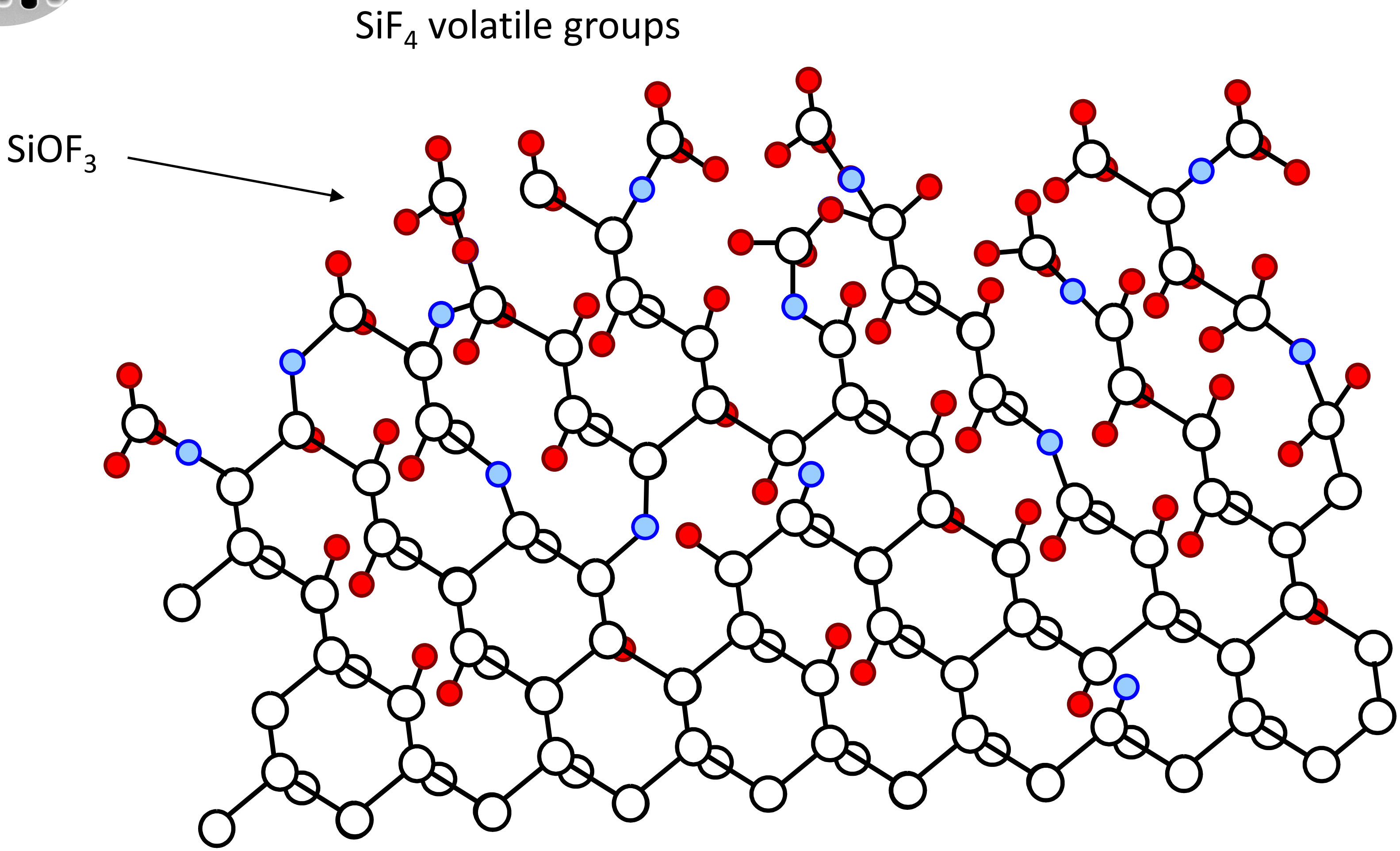




- **Decrease of SiO_xF_{4-x}** contribution with temperature
- Appearance and increase of **Si matrix contribution**

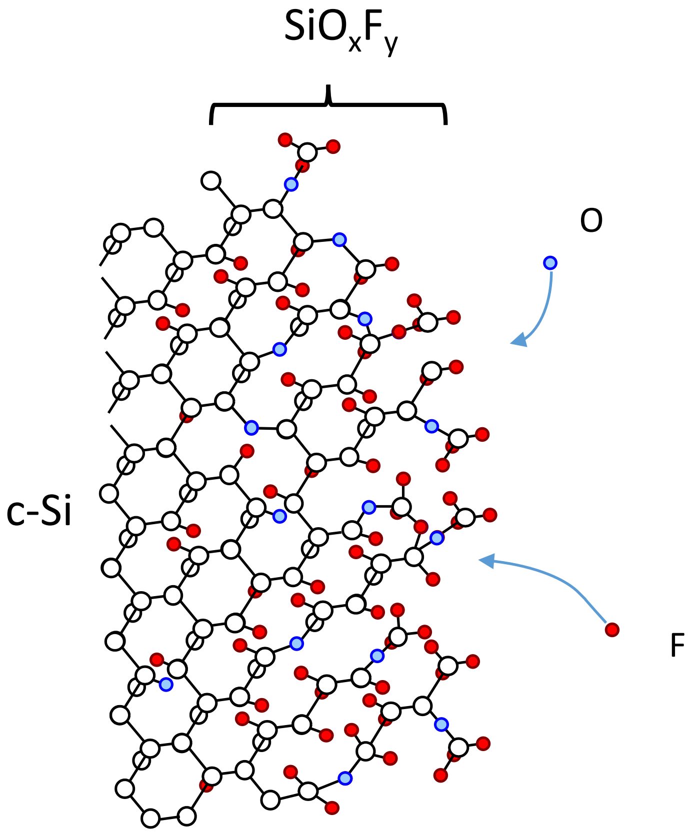
- **$[O]_{at}$** remains almost **constant** from -75°C
- **$[F]_{at}$ decreases** from -75°C

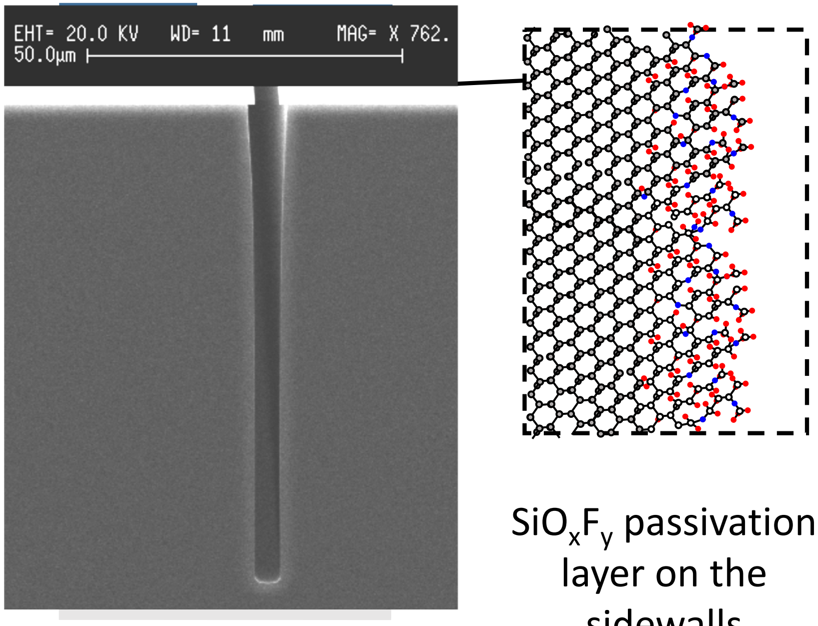
Silicon matrix after SF_6/O_2 overpassivating plasma



Summary on the SiO_xF_y Passivation layer in SF_6/O_2 plasma

- Thin SiO_xF_y formation by SF_6/O_2 plasma at low temperature

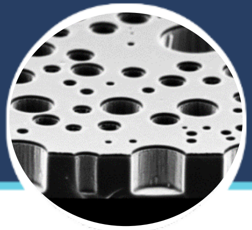




SiO_xF_y passivation layer on the sidewalls

- In **SF_6/O_2 plasma, fluorine radicals** will form SiF_x sites at the silicon surface and oxygen will react with SiF_x sites to form a thin SiO_xF_y layer.

  ⇨ **quite fragile passivation** layer.



Passivation layer formation by SiF_4/O_2 plasma

Passivation layer construction with SiF_4

Two cavity test experiments to study the passivation layer formation

Principle : - we start with an isotropic etching (**Ini**tial profile)

- we try to form the passivation layer with SiF_4 and O_2

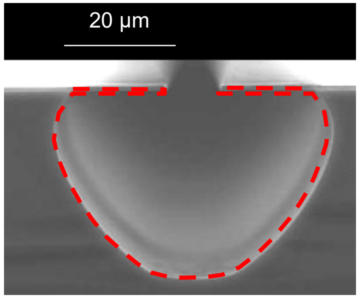
INI : Isotropic etching

- 10 min
- SF_6: 200 sccm
- Source: 1000 W
- Bias: 0 V
- -83°C

END : Additional etching

- 3 min
- SF_6: 200 sccm
- Source: 1000 W
- Bias: 37 V
- -83°C

Isotropic etching continues



Reference profile

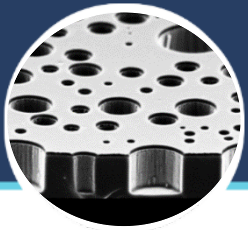
Passivation

- 1 min
- SiF_4/O_2 65%
- Source: 1000 W
- Bias: 37 V
- -83°C

END

Efficient passivation layer

SiF_4/O_2 plasma can be used to form an efficient passivation layer.



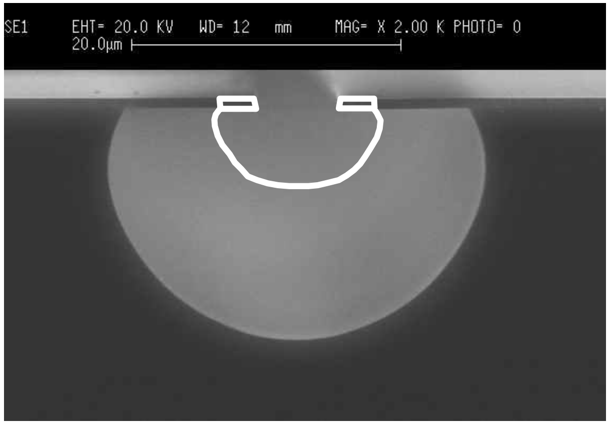
STiGer process

Alternation of isotropic SF_6 etching steps and SiF_4/O_2 passivation steps

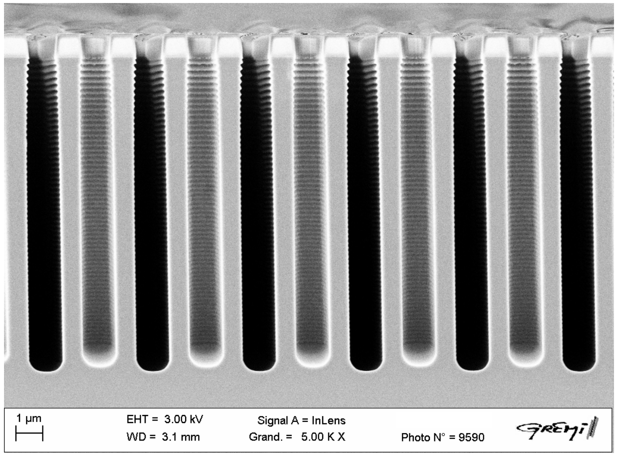
4 alternances 1min SF_6 etching - SiF_4/O_2 deposition + a final 1 min etch

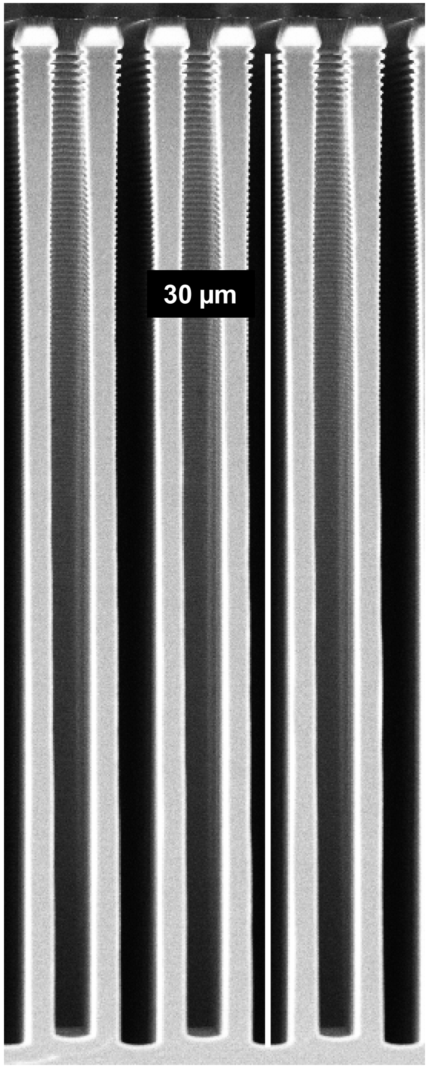
–83°C

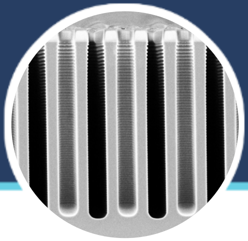
Same experiment at 0°C



Anisotropic microstructures can be obtained by alternating SF_6 etching and SiF_4/O_2 passivation steps, but it only works at cryogenic temperature







In-situ X-Ray Photoelectron Spectroscopy

OPTIMIST Platform

- **SiF_4 / O_2** plasma experimental conditions:

a-Si sample ; 30 s ; SiF_4 /O_2 : 25 % ; 3.0 Pa ; 200 W ICP power ; no bias.

- **SiO_xF_y layer growth** at 3 different temperatures : -40, -65 and -100°C

- At -40°C, 17.1% [F] ; 23.6% [O]

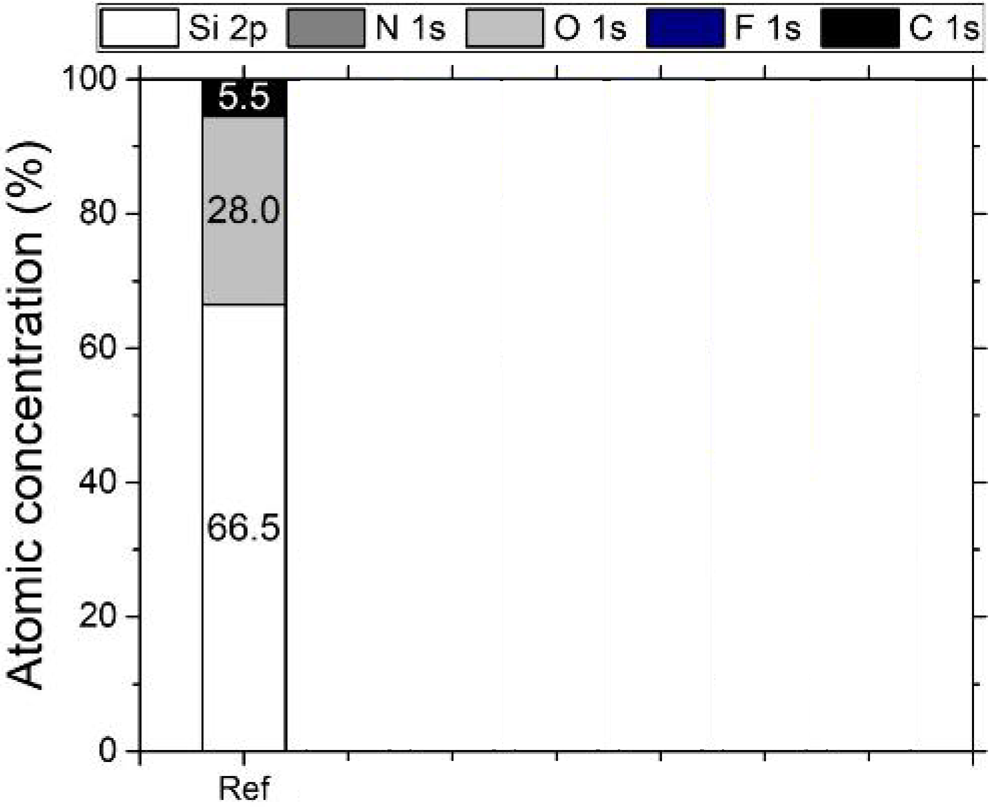
After heating: no significant change

- At -65°C, 20.0% [F] ; 22.8% [O]

After heating: a little decrease of [F]

- At -100°C, 52.3% [F] ; 18.0% [O] ; 15% [N] (stoechiometry of ~$SiOF_3$)

After heating: a large part of Fluorine based species has desorbed



G. Antoun *et al* 2022 *ECS J. Solid State Sci. Technol.* **11** 013013

Role of SiF_x physisorption at low temperature

- 2014 : Molecular dynamics by Stefan Tinck from PLASMANT laboratory (Antwerpen)

S. Tinck et al. J. Phys. Chem. C 2014, 118, 30315−30324

Fluorine – silicon surface reactions at cryogenic temperature

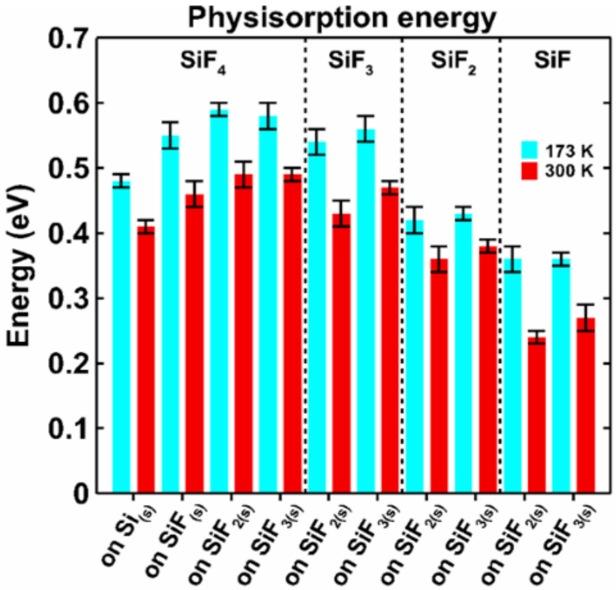
Calculated **probabilities for immediate sticking** upon impact of various impinging species on different surfaces (1)

Sticking : creation of a chemical bond (within 12.5 ps in this work).

Impinging species	on Si		on SiF		on SiF_2		on SiF_3	
	300 K	173 K	300 K	173 K	300 K	173 K	300 K	173 K
F	0,98	0,98	0,92	0,93	0,59	0,61	0,23	0,25
Si	1	1	1	1	0,41	0,40	0,20	0,19
Si_F	0,88	0,89	0,49	0,50	0	0	0	0
SiF_2	0,51	0,50	0,18	0,19	0	0	0	0
SiF_3	0,37	0,37	0,06	0,06	0	0	0	0
SiF_4	0	0	0	0	0	0	0	0
F_2	1	1	1	1	0,77	0,77	0,3	0,31

⇨ Probabilities for Immediate Sticking do not depend on temperature from 173 to 300 K !

⇨ Long thermal desorption time at low temperature as compared to room temperature ⇨ longer residence time of the species at the surface

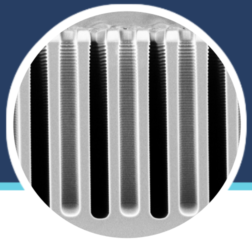


$$k = Ae^{-\frac{E_a}{k_BT}}$$

Rate constant for thermal desorption

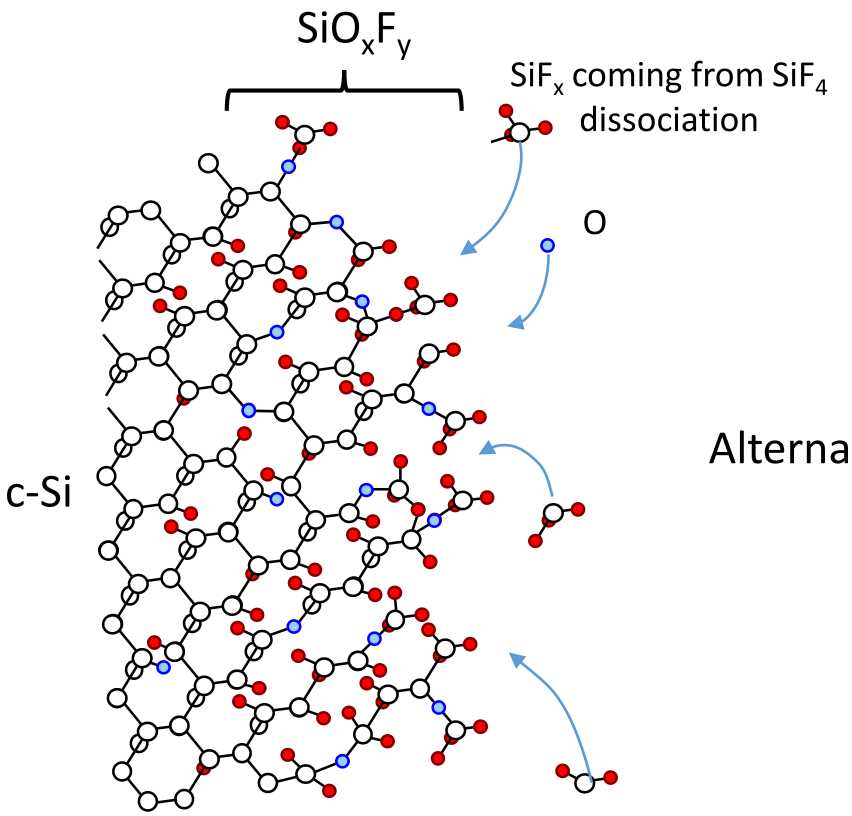
E_a increases by lowering T, due to smaller oscillation amplitudes between adsorbent and surface.

T. Lill et al. JVSTA 41 023005 (2023)



Conclusion on SiF_4/O_2 plasma at low T

- It is possible to reinforce the passivation layer by using SiF_4/O_2 plasma steps

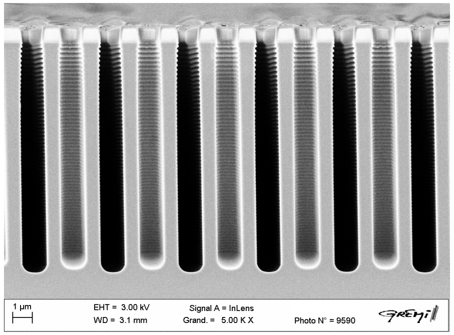


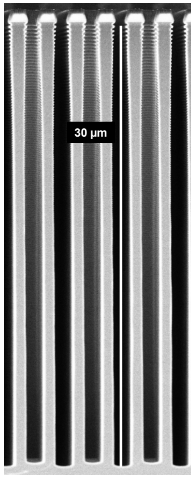
- **SiF_x radicals** coming from SiF_4 dissociation deposit on the sidewalls with a much longer residence time. They react with oxygen atoms to create a thicker SiO_xF_y layer.

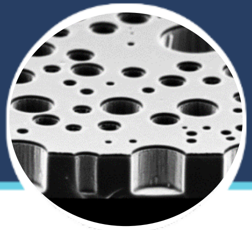
  ⇨ **more robust** passivation layer.

⇨ STiGer process

Alternation of SF_6 plasma – SiF_4/O_2 plasma







Passivation steps using CF_4 plasma instead of C_4F_8

C_xF_y plasma for passivation

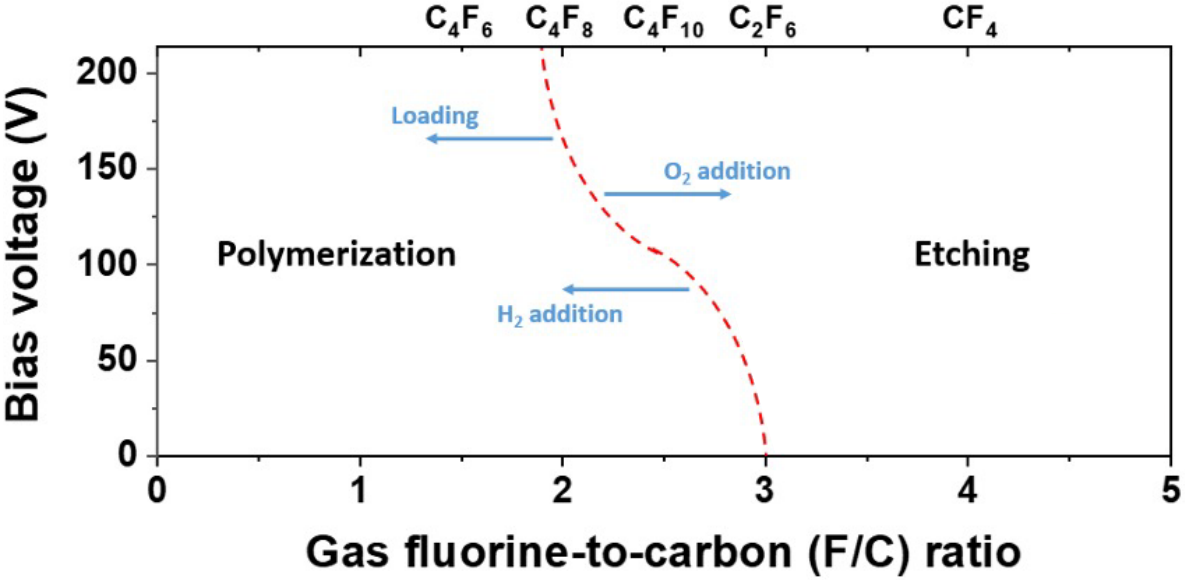
- C_4F_8 is the main gas used for passivation steps at room temperature in the so-called Bosch process to cover the sidewalls with a CF_x protective layer

- Low F/C ratio gases are highly polymerizing

- Deposition regime unless a high bias voltage is applied

- But, CF_x deposits everywhere even on reactor walls, leading to process drifts.

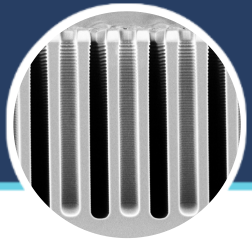
- Cleaning steps are needed



Adapted from J. W. Coburn and H. F. Winters, Plasma etching—A discussion of mechanisms, J Vac Sci Technol 16, 391 (1979)

- The boundary line can be shifted to the right by decreasing the substrate temperature

- Is it possible to use **CF_4 instead of C_4F_8** at low temperature ?



CF_4 plasma at cryogenic temperature

J. Nos et al. Appl. Phys. Lett. 126, 031602 (2025)

Etching step: 3 s

300 sccm SF_6, 3 Pa, 1500 Ws, -135 Vb

x200

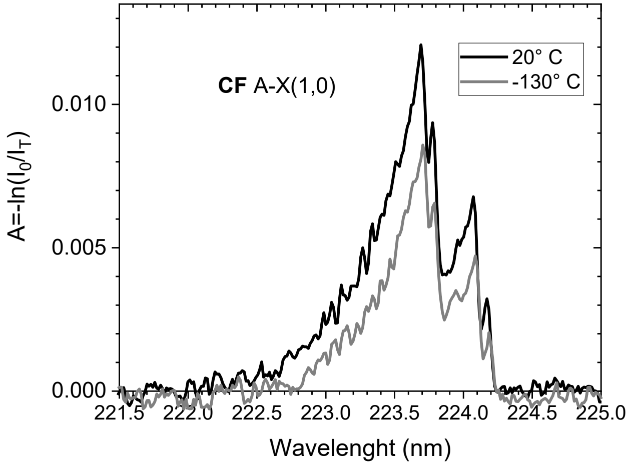
Passivation step: 2 s

20 sccm CF_4, 1 Pa, 1500 Ws, -65 Vb

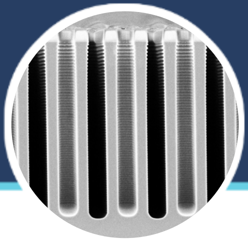
=> Strong CF_x deposition at -100°C

=> Enhanced passivation at -100°C

UV absorption experiments
with G. Cunge and M. Kogelschatz (LTM)

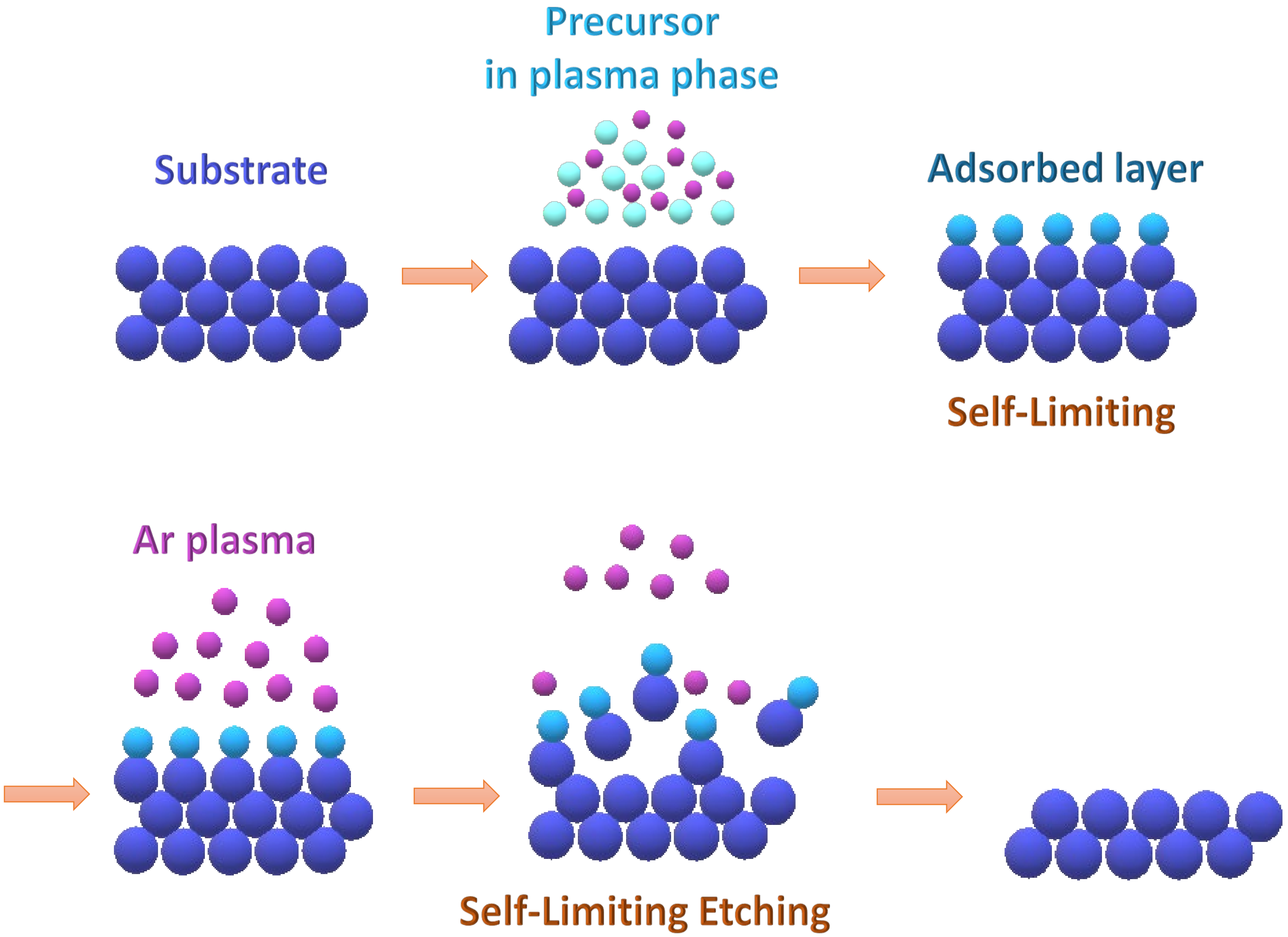


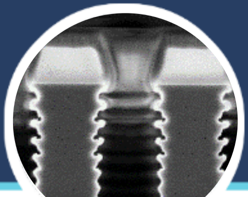
- CF concentration drops at low wafer temperature, which shows that CF sticks more efficiently at low temperature. This is not the case for CF_2.
- CF_4 is a good candidate to passivate the trench sidewalls without depositing on the reactor walls.



Cryo-Atomic Layer Etching

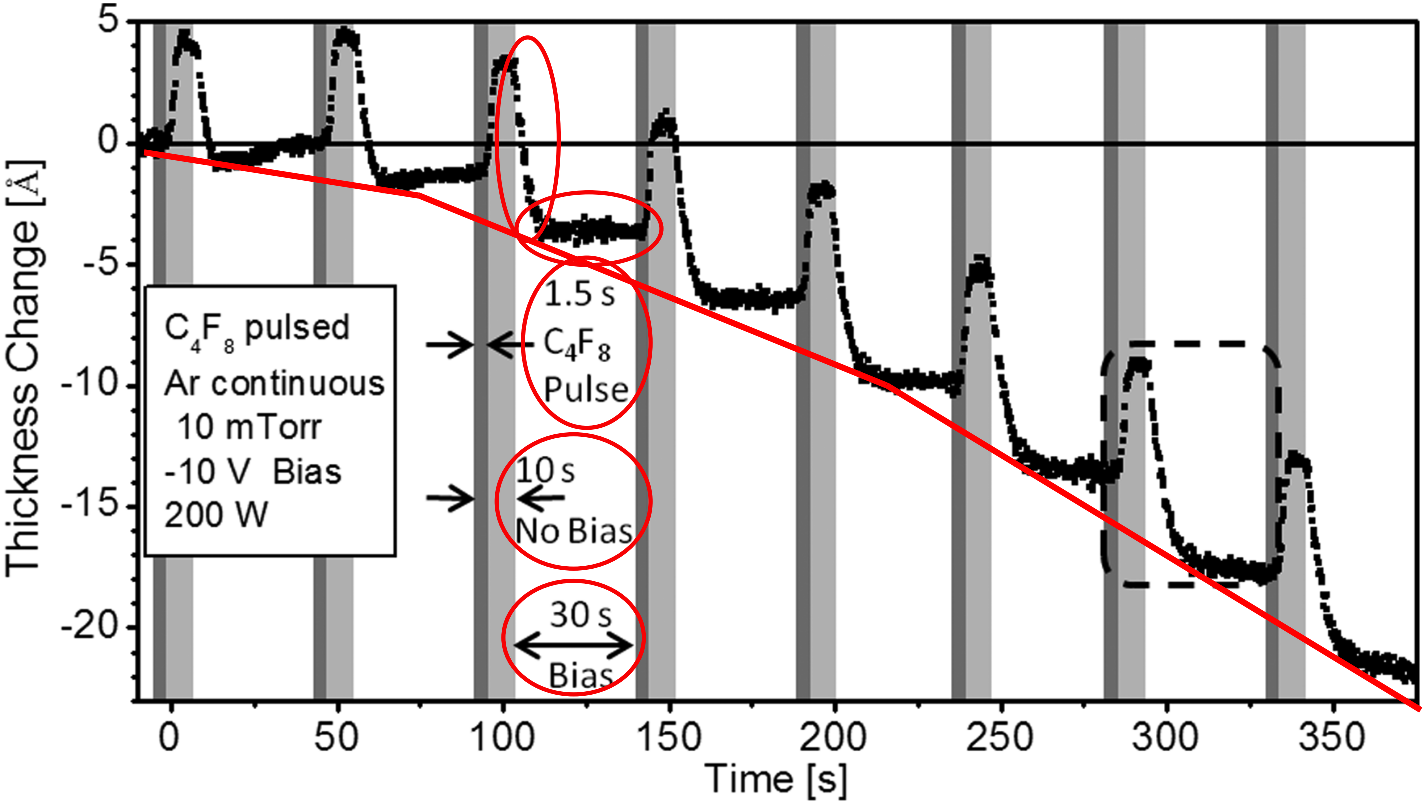
Principle of Atomic Layer Etching





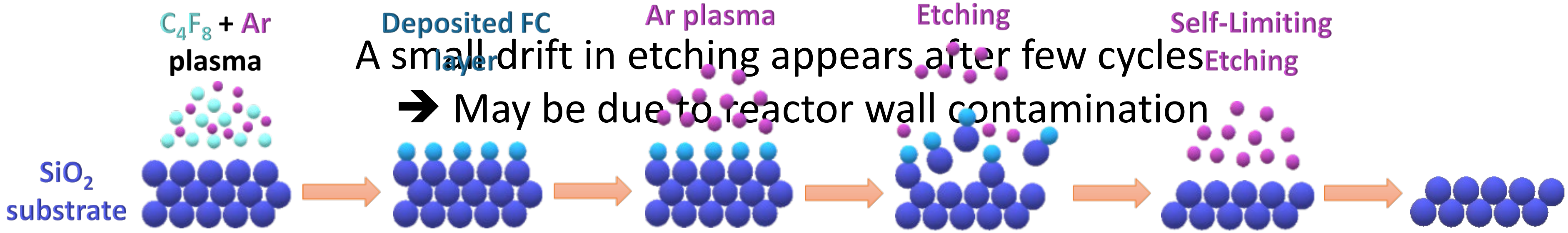
Atomic Layer Etching for SiO_2

T=10°C



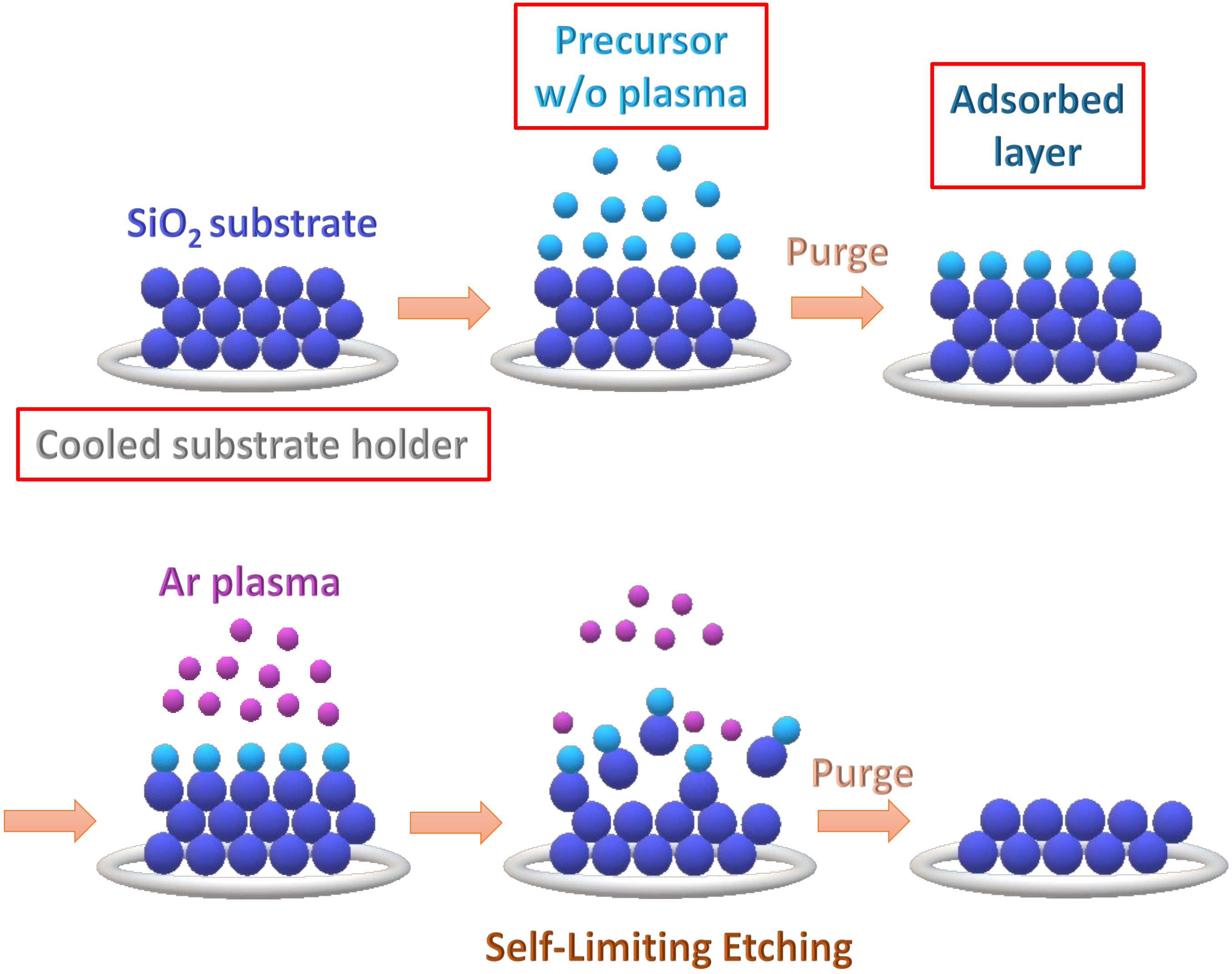
A small drift in etching appears after few cycles

➔ May be due to reactor wall contamination



D. Metzler *et al.*, J. Vac. Sci. Technol. Vac. Surf. Films **32**, 020603 (2014)

Principle of Cryo-Atomic Layer Etching for SiO_2



SiO_2 substrate

Cooled substrate holder

Precursor w/o plasma

Purge

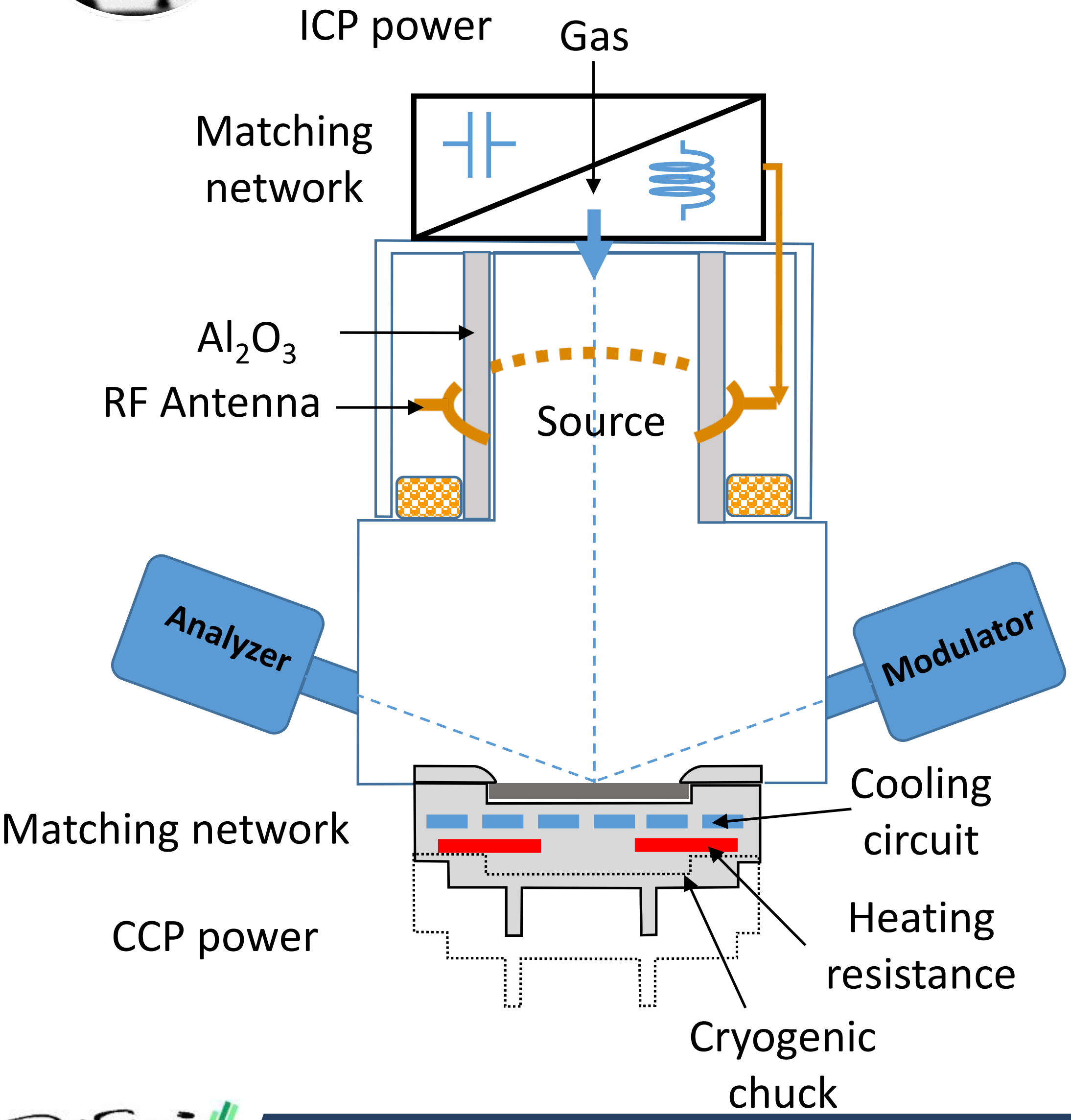
Adsorbed layer

Ar plasma

Purge

Self-Limiting Etching

Inductively Coupled Plasma (ICP) reactor



Parameter range:

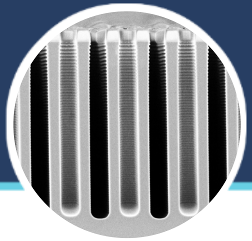
- Fast ALD valves for C_4F_8 gas injection

- Pressure : 1 – 10 Pa
- Power : 500 – 3000 W
- Bias : 0 – 100 V
- C_4F_8 : 0 – 14 sccm
- Ar : 0 – 280 sccm
- Temperature : -150 – 30 °C

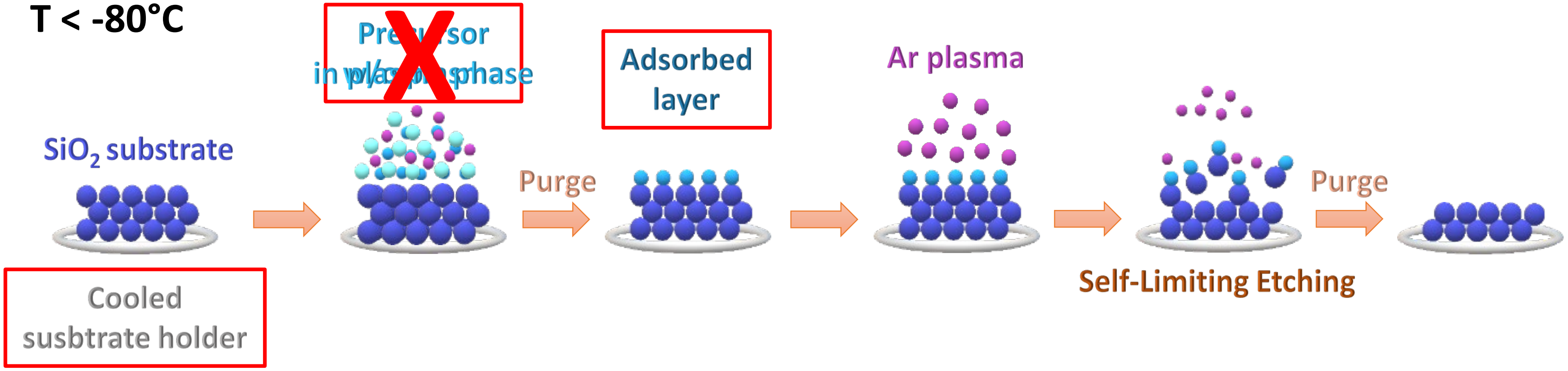
Diagnostic:

- In-situ ellipsometry
- Mass spectrometry

Principle of Cryo-Atomic Layer Etching for SiO$_2$



T < -80°C



SiO_2 substrate

Cooled susbtrate holder

Precursor in plasma phase

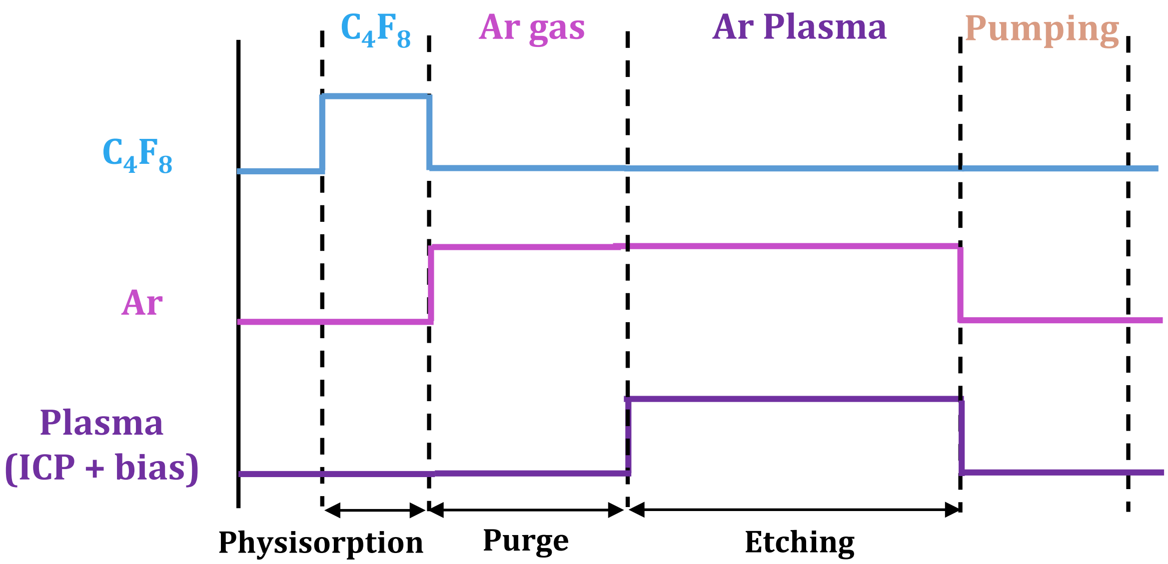
Purge

Adsorbed layer

Ar plasma

Purge

Self-Limiting Etching



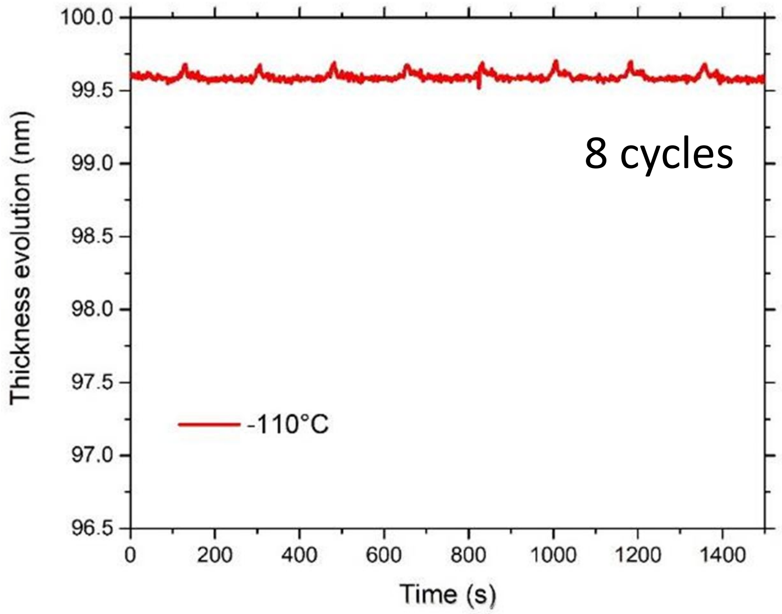
Proof of principle

Adsorption
- **C_4F_8 gas flow**
- **10 s**

Purge
- **Ar gas flow**
- 30 s

Etching
- **Ar plasma**
- 2 min
- Source: 400 W
- Bias: -20 V

Pumping
- **w/o gas**
- 15 s

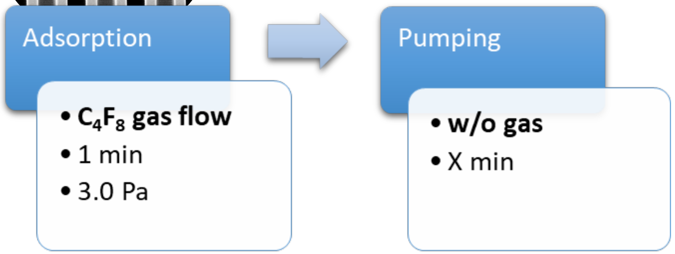


EPC < 0.5 nm/cycle

No etching at -110 °C (and higher temperatures)

G.Antoun et al, Appl. Phys. Lett. 115, 153109 (2019)

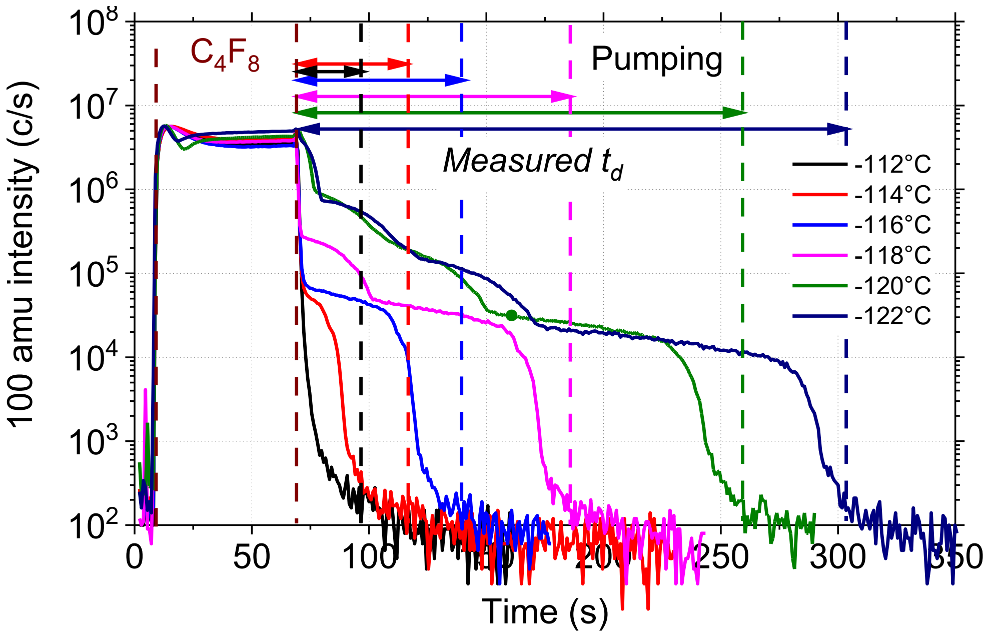
Cryo-ALE of SiO_2 based on C_4F_8 physisorption

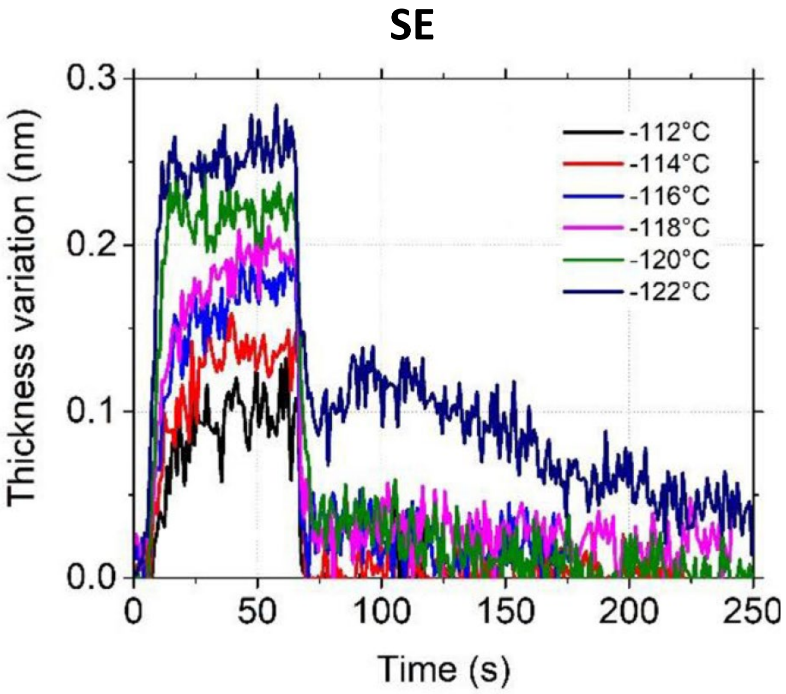


Adsorption
- **C_4F_8 gas flow**
- 1 min
- 3.0 Pa

Pumping
- **w/o gas**
- X min

- **100 amu** peak corresponding to **$C_2F_4^+$** signal was monitored in Multiple Ion Detection (MID) mode by mass spectrometry
- Adsorption of C_4F_8 on **SiO_2** was monitored by ellipsometry

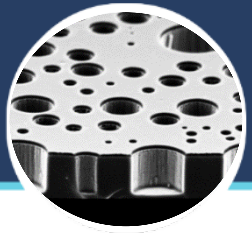




At constant pressure, by decreasing temperature:
- Several desorption rates are observed

- Desorption rate ↘
- **Residence time on the substrate surface ↗**

G. Antoun *et al.*, Sci. Rep. 41598 (2020) 79560



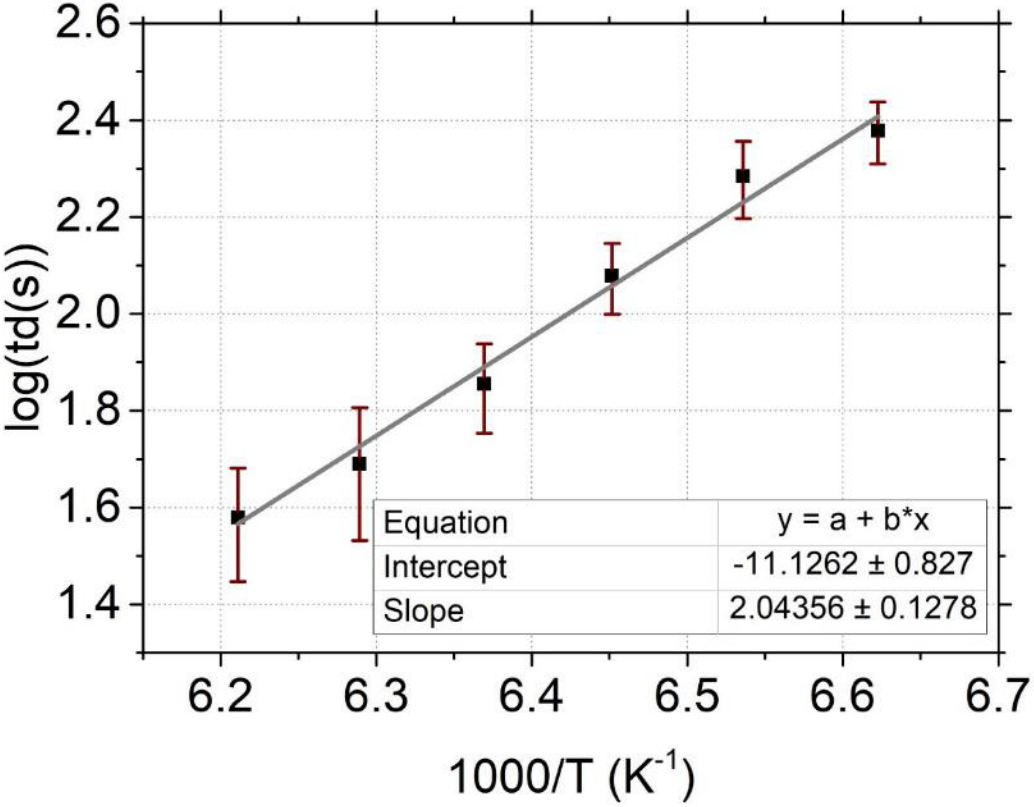
Desorption rate

$$t_d = t_d^0 exp^{E_d/k_BT}$$

t_d: residence time (s)

t_d^0: attempt time of the particle for desorption (s)

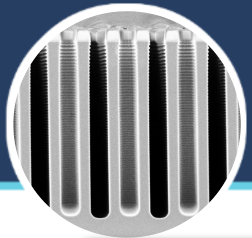
E_d: desorption energy (eV)



Equation	y = a + b*x
Intercept	-11.1262 ± 0.827
Slope	2.04356 ± 0.1278

t_d^0 = 1.0x10^{-11} s

E_d = 0.404 eV.



Cryo-ALE of SiO_2 based on C_4F_8 physisorption at higher temperature

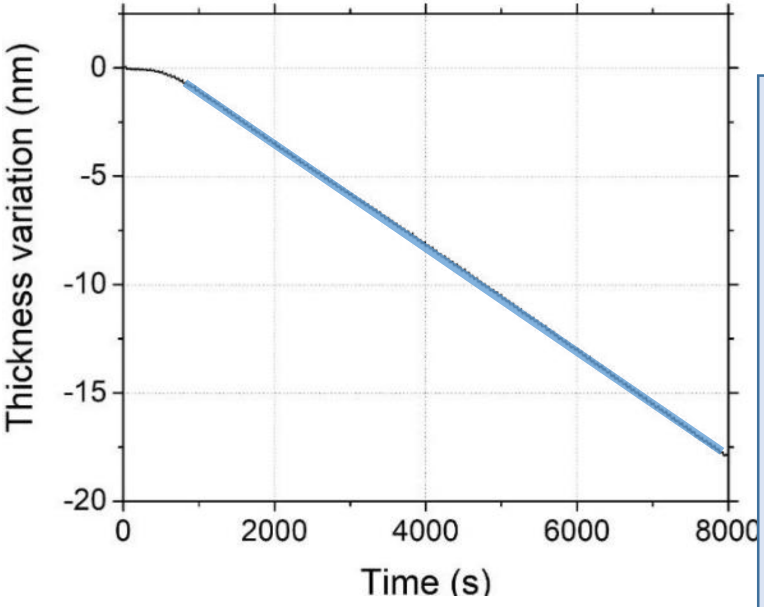
Adsorption
- C_4F_8 gas flow
- 20 s

Purge
- **Ar gas flow**
- **3 s**

Etching
- **Ar plasma**
- **15 s**
- Source: 400 W
- **Bias: -20 V**

Pumping
- **w/o gas**
- 15 s

150 cycles at -90°C

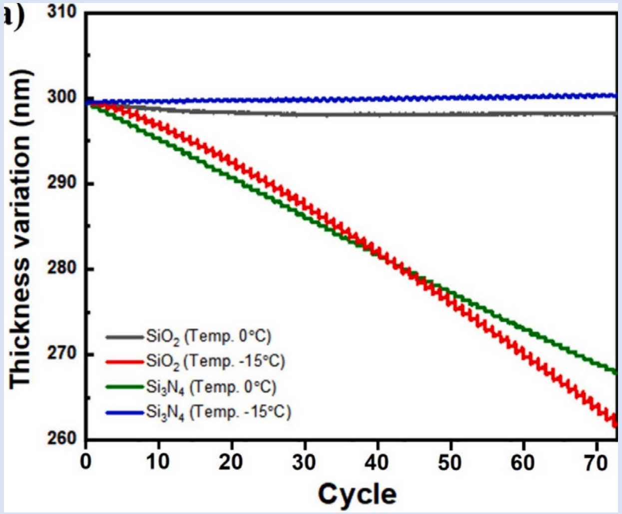


G.Antoun et al, Scientific Reports | (2021) 11:357

- **No drift observed due to reactor wall contamination**
- ≈ 18 nm etched in 150 cycles

Sungkyunkwan University (South Korea)

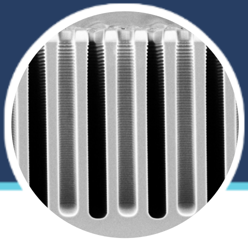
Same type of experiments with C_6F_6 which adsorbs at higher temperature. High etch selectivity obtained between SiO_2 and Si_3N_4.



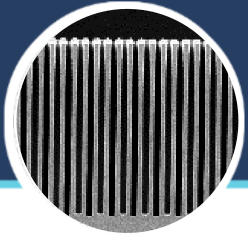
D I Sung et al Applied Surface Science 670 (2024) 160574

Conclusion on physisorption based cryo ALE

- **Cryo Atomic Layer Etching of SiO_2** was shown by **physisorbing C_4F_8** at the surface at **-120°C** followed by Ar plasma.
- A **threshold temperature** has to be reached to enable cryo-ALE.
- **Residence time of physisorbed species** can be determined by mass spectrometry.
- **Ar plasma** has to be ignited before the end of the residence time.
- Reactor wall **contamination** is significantly **reduced**. **The etch per cycle** remains quite **regular**, even after many cycles.
- **Self-Limiting Etching** is achieved.

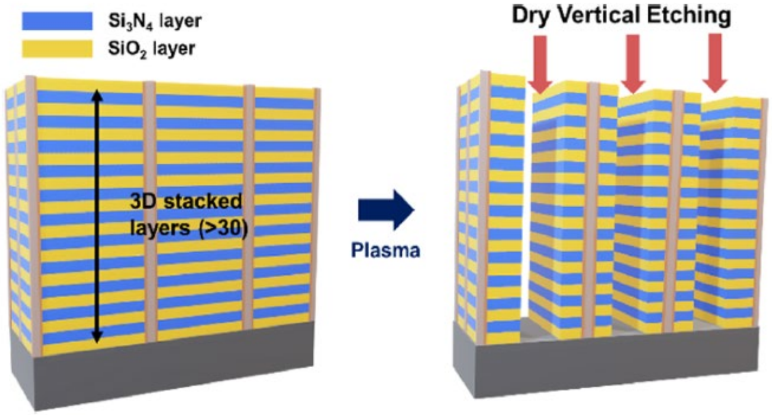


What makes cryogenic etching popular again in the industry ?



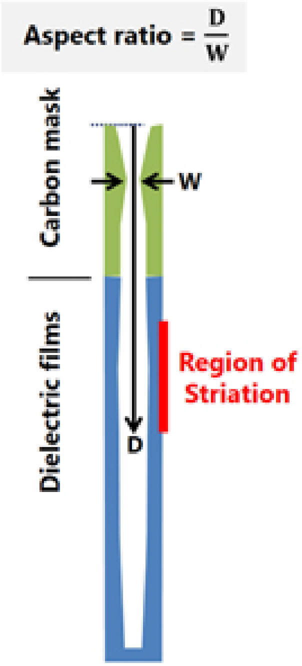
SiO_2 and Si_3N_4 deep etching

- Need to etch very high aspect ratio holes on Si_3N_4 and SiO_2 for 3D NAND technology.

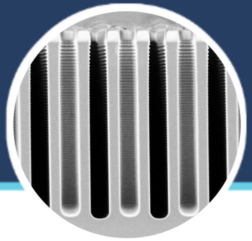


From H.I. Lee et al. ACS Sustainable Chem. Eng. 9, 4948, 2021

- Usually, CF-based plasmas (C_4F_8, CHF_3…) are used to etch SiO_2 and Si_3N_4 at room temperature.
- However, some deposition occurs on the carbon mask which leads to striation on the dielectric film
- This aperture reduction increases the ARDE effect.



Mitsuhiro Omura et al 2019 Jpn. J. Appl. Phys. 58 SEEB02

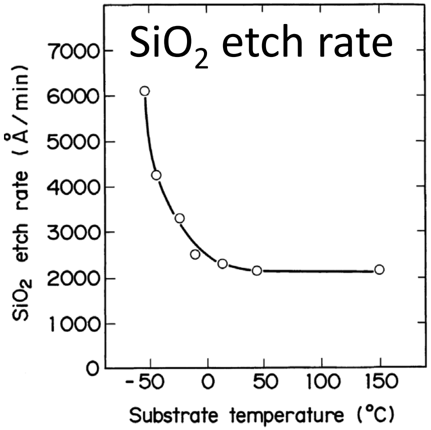


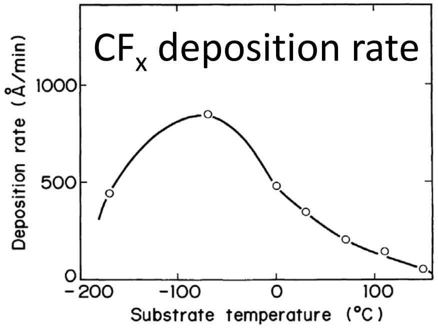
Why using cryoetching ?

- Increase of etch rate of SiO_2 at low T in CHF_3 plasma.

Conditions :
CHF_3 gas
Magnetron RIE system
P = 40 mTorr
RF power density : 1.4 W/cm²

T. Ohiwa, et al. Jpn. J. Appl. Phys.31. 405-410(1992)

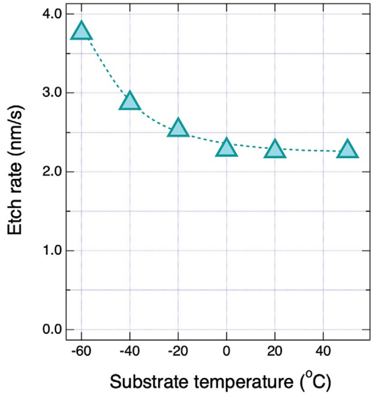


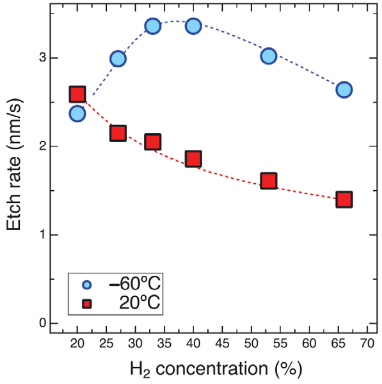


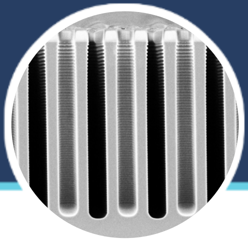
- CF_4/H_2 plasma cryoetching : etch rate increases by adding H_2

- They showed by in-situ FTIR that HF was forming at the surface at low temperature

S-N. Hsiao et al. Small Methods 2400090 (2024)







High aspect ratio holes in Si_3N_4/SiO_2 stacked layers

- Pure HF and H_2O plasma mixture can be used to etch SiO_2 and Si_3N_4 at low temperature (below -40°C) with high energy ions.

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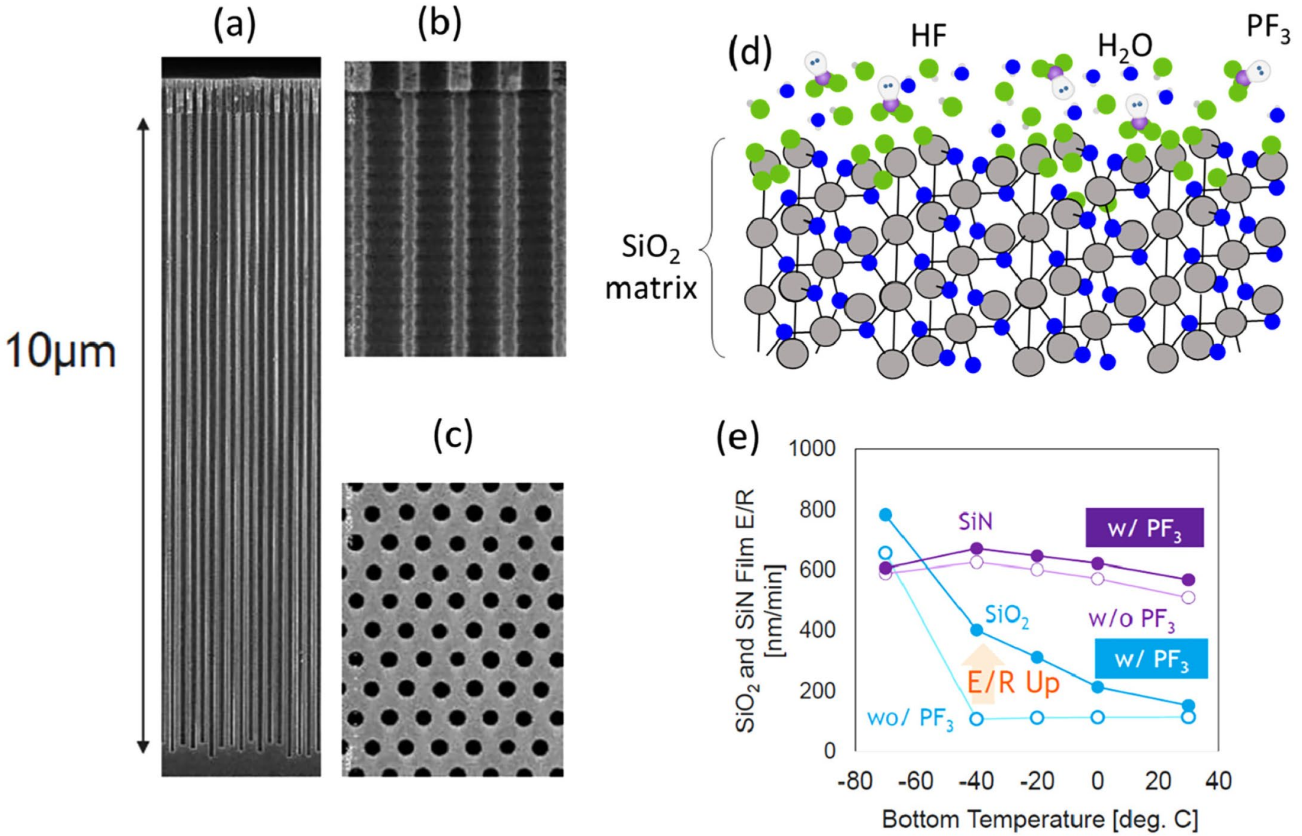
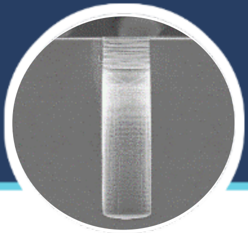
TOKYO ELECTRON

84% Reduction of Global Warming Potential



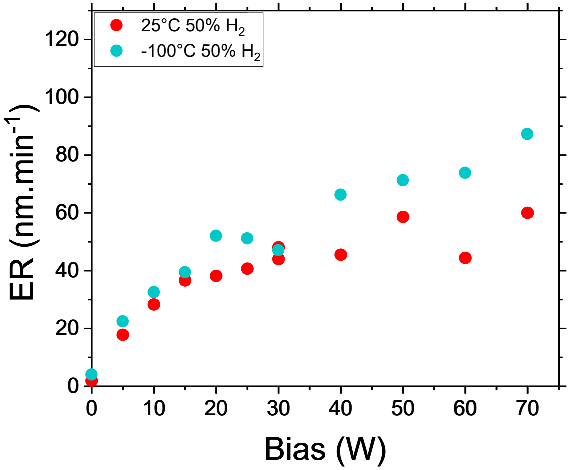
Y. Kihara et al. 2023 IEEE Symposium on VLSI Technology and Circuits (VLSI Technology and Circuits), Kyoto, Japan, 1-2 (2023).

G. S. Oehrlein et al., "Future of plasma etching for microelectronics: Challenges and opportunities" JVST. B 42, 041501 (2024)

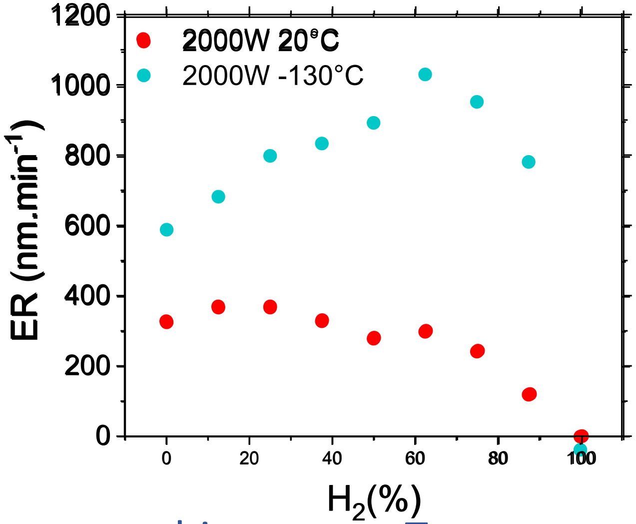


SiO_2 cryoetching in SF_6/H_2 plasma

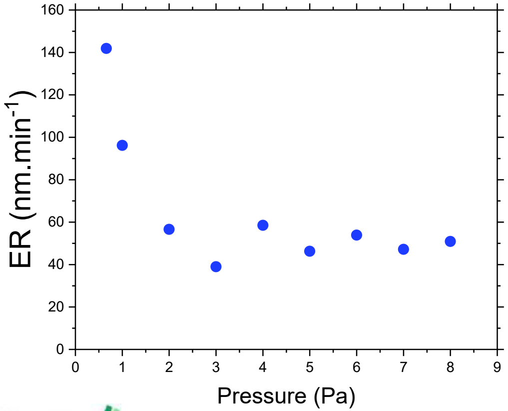
- SiO_2 cryoetching versus bias power (1,6 Pa, 1000 W source)



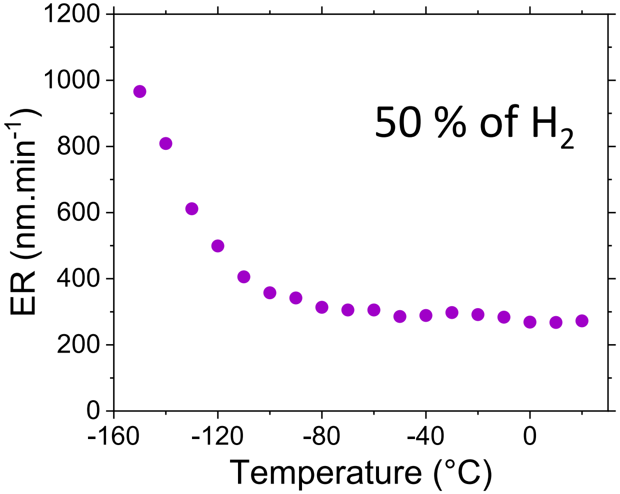
- SiO_2 cryoetching versus H_2 % (0,6 Pa, 150 W bias)

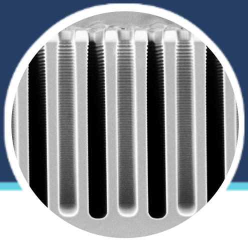


- SiO_2 cryoetching versus pressure (-100°C, 1000W source, 150 W bias)



- SiO_2 cryoetching versus T (0,6 Pa, 150 W bias)





What are the advantages of cooling the substrate ?

- In terms of physical and chemical mechanisms, cooling the substrate can :
  - Increase the **residence time** of physisorbed species
  - **Promote chemical reactions** at the surface
  - **Modify the stoichiometry** of the deposited layer
  - Create a mix between **physisorbed** and **chemisorbed** species at the surface
  - Limit surface diffusion
- In terms of process, cooling the substrate can:
  - **Avoid contamination** of the reactor walls
  - Increase the **etch rate**
  - Increase the **selectivity**
  - **Protect porous material** during etching

PlaCEP workshop (Plasma Cryogenic Etching Processes)

1st edition in 2022 : Orléans (France)
2nd edition in 2024 : Leuven (Belgium)
3rd edition in 2025 : *New Taipei (Taiwan)*

PlaCEP

The ***3rd PlaCEP Workshop*** will take place at **Ming Chi University of Technology in New Taipei City, Taiwan** in **June 25-28, 2025**

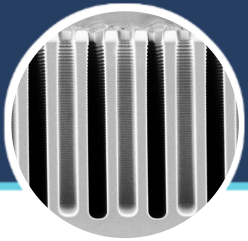
IPTJC 2025
International Plasma Technology Joint Conference

organized within the International Plasma Technology Joint Conference 2025 (IPTJC-2025)

Cryogenic etching processes of silicon, dielectrics, cryo-ALE, modeling and simulation

IPTJC2025
The International Plasma Technology Joint Conference 2025
June 25 to 28, 2025
Ming Chi University of Technology, New Taipei, Taiwan

Acknowledgment



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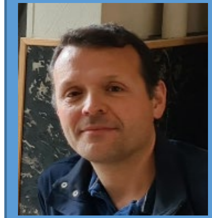

Philippe
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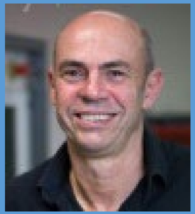

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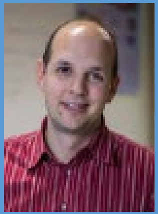

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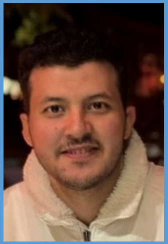

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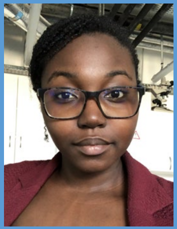

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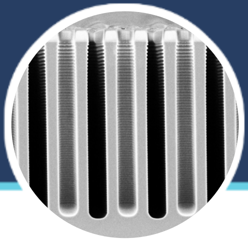

Thank you !