Cryo-ALE of Si based on SF_6 Physisorption

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Introduction:

Cryo-ALE: Atomic Layer Etching process performed at cryogenic temperatures (-70°C to -120°C)

Previous (C_4F_8 + Ar) cryo-ALE research campaign on SiO_2: Study of C_4F_8 physisorption

➔ Obtention of a self-limiting etching regime at T = -120°C (≈ 1 nm/cycle)

➔ No particular etching selectivity of SiO_2 over Si or Si_3N_4

Objectives:

Cryo-ALE process optimization: Comparison of etching properties obtained with SF_6 and C_4F_8 physisorptions at similar process conditions

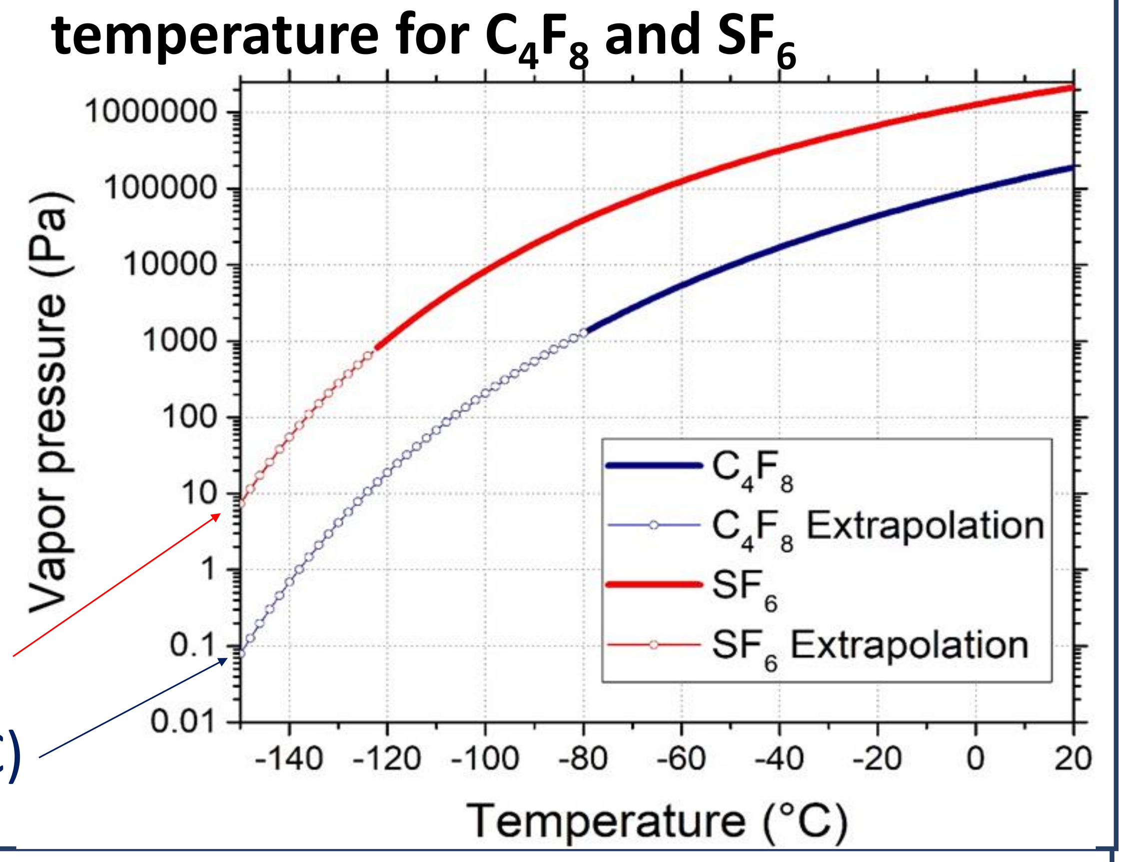
Study of SF_6 physisorption: Study of plasma-surface interactions during cryo-ALE processes based on SF_6 physisorption

At low pressures (1 to 3 Pa):

SF_6 vapor pressure equilibrium (≃-150°C)

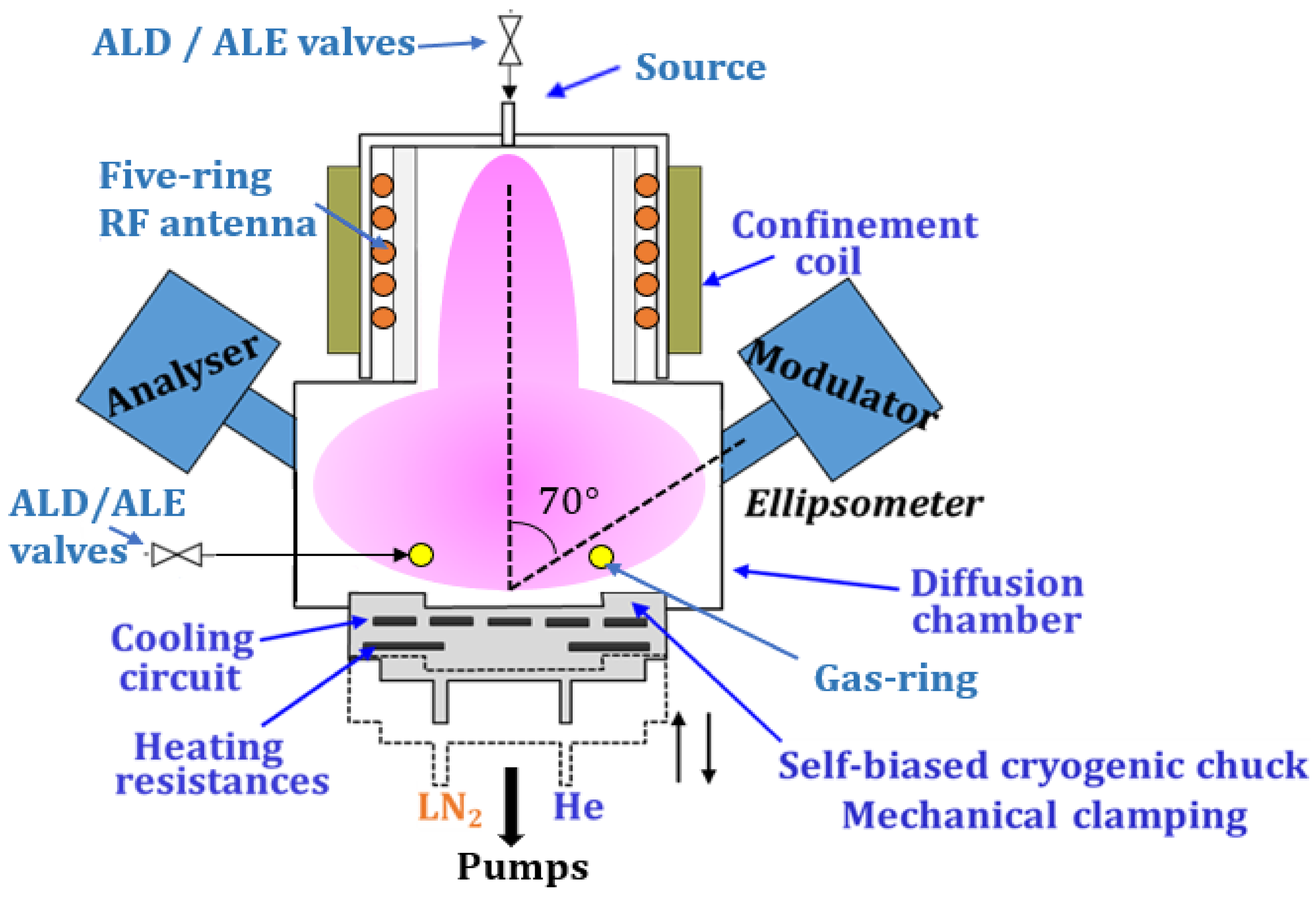
C_4F_8 vapor pressure equilibrium (≃-130°C)

Figure 1: Vapor pressure in relation to temperature for C_4F_8 and SF_6



Experimental equipment:

Etching equipment: Oxford Plasma Pro 100 Cobra (ICP reactor)

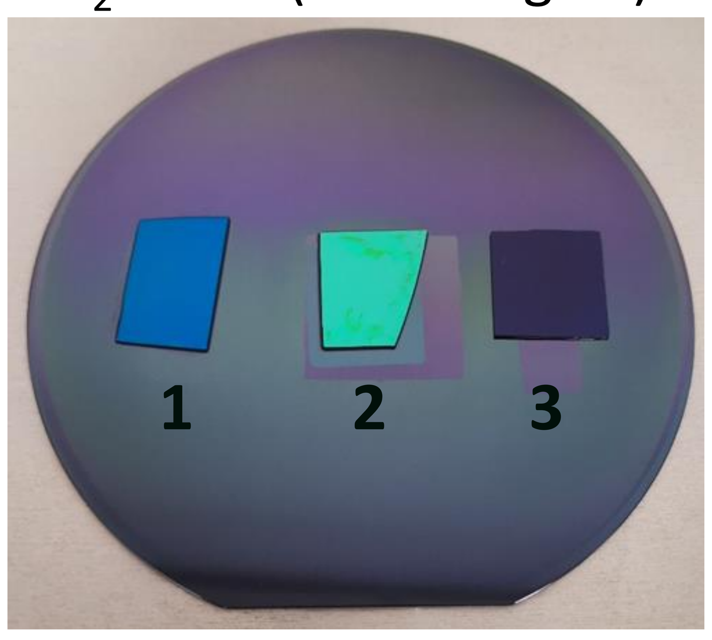


Characterization tools:

Ellipsometry: in-situ Horiba Jobin Yvon ellipsometer

➔ Chemical composition and thickness of the etched substrate

Samples: Use of p-Si, SiO_2 and Si_3N_4 coupons (2x2 cm) glued on a 4'' or 6'' SiO_2 wafer (thermal glue)



1: Silicon nitride (Si_3N_4)

2: Polycrystalline silicon (p-Si)

3: Silicon dioxide (SiO_2)

Experimental Results:

(SF_6 + Ar) cryo-ALE process parameters:

1) SF_6 Physisorption: 10 s; 3 Pa;

SF_6 (50 sccm) Gas-ring injection

2) 1st Purge (Ar gas): 15 s; 3,4 Pa;

Ar (100 sccm) Source injection

3) Ar Etching: 120 s; 3,4 Pa; 400 W_S; 0 W_B;

Ar (100 sccm) Source injection

4) 2nd Purge (Pumping): 15 s; 0 Pa

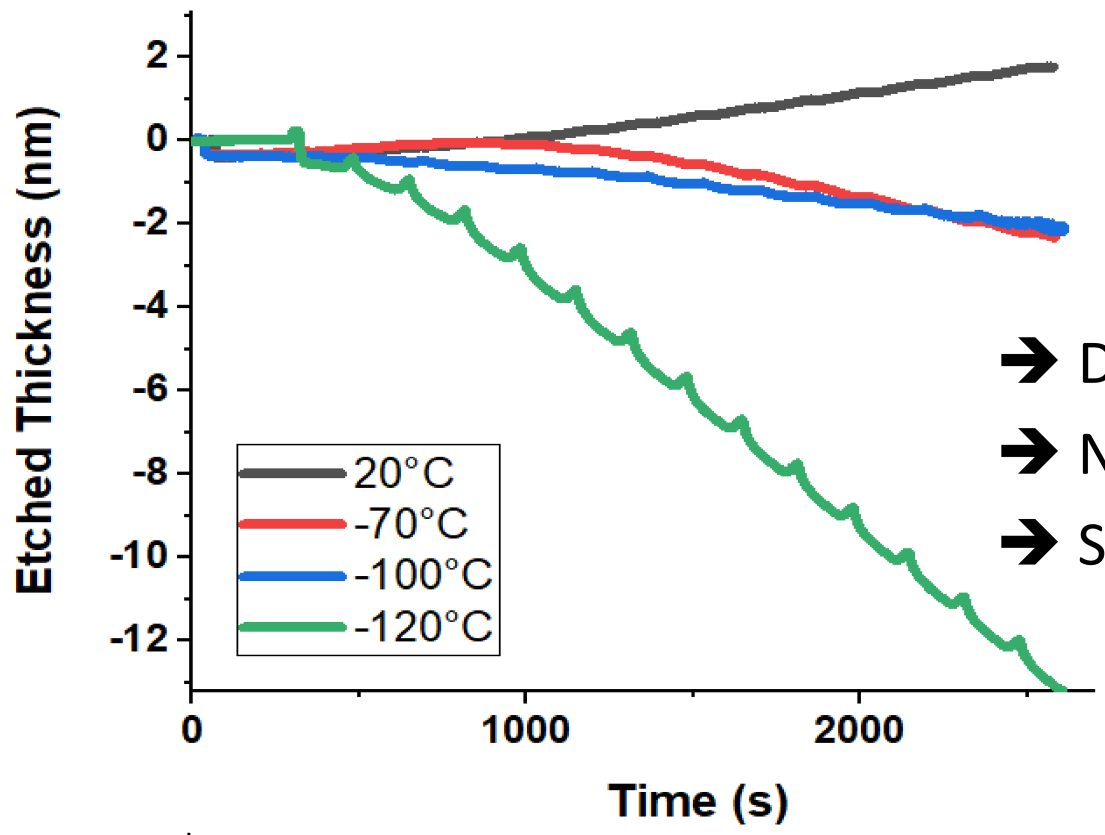


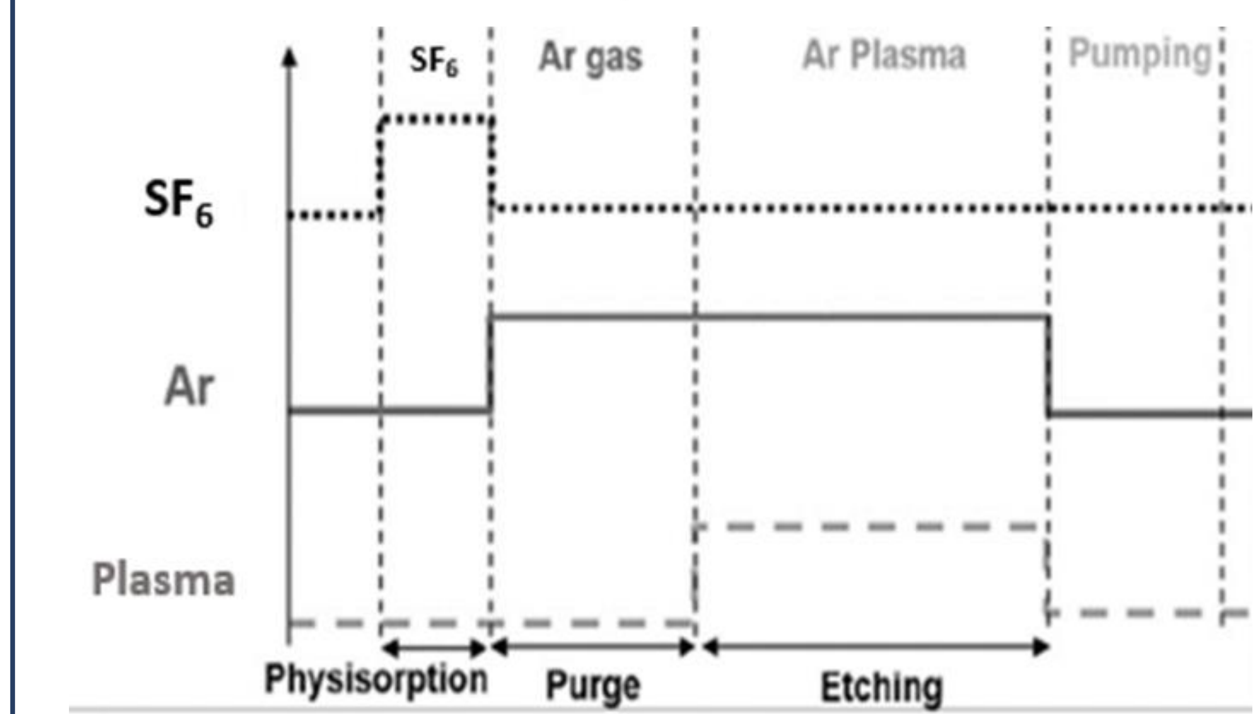
Figure 2: (SF_6 + Ar) cryo-ALE of SiO_2 at different temperatures

➔ Deposition regime at 20°C

➔ No significant etching at -70°C and -100°C

➔ Self-limiting quasi-ALE etching regime at -120°C

Time chart of the (SF_6 + Ar) ALE process cycle



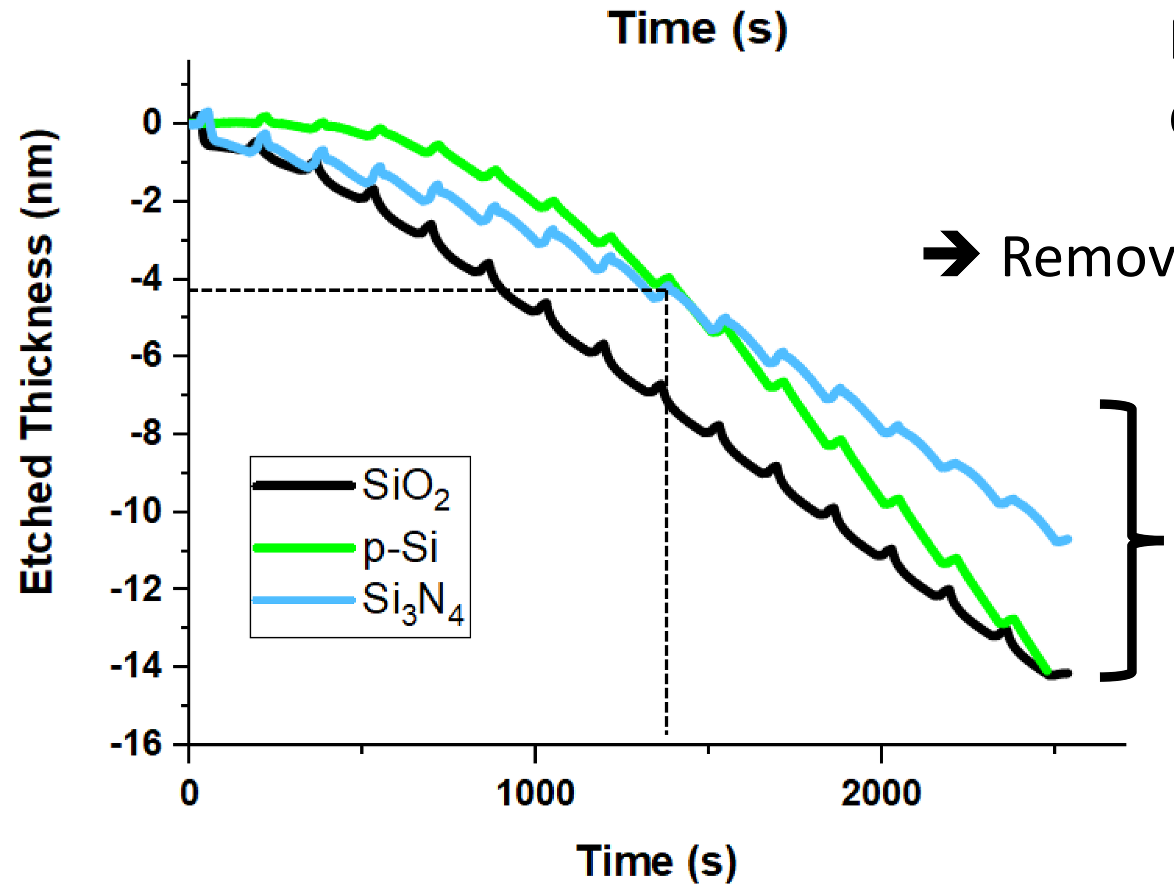


Figure 3: (SF_6 + Ar) cryo-ALE of different Si-based materials at -120°C

➔ Removal of native oxide at p-Si and Si_3N_4 surface

Materials	EPC (nm/cycle)
p-Si	1,4
SiO_2	1,1
Si_3N_4	1,1

Conclusion and perspectives:

➔ Observation of a quasi-ALE etching regime at T=-120°C for p-Si, SiO_2 and Si_3N_4 (≈ 6 monolayers of Si / cycle); The increased surface residence time of SF_6 at -120°C allows etching during the Ar etching step; No etching selectivity between Si, SiO_2 and Si_3N_4

➔Further characterizations (Plasma probes, XPS spectroscopy, Optical spectroscopy and Mass spectrometry) to better understand plasma-surface interactions during SF_6 physisorption at cryogenic temperatures in order to optimize the process.

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