Innovative and environmental friendly Fluorine F_2 based cleaning process to replace C_2F_6, CF_4 and NF_3 as cleaning gas

SPCC Conference

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Solvay Special Chem

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Outline

- Intro – PECVD cleaning technology
- Drivers for F_2-based chamber cleaning
- Facilitation example for F_2-gas
- Hardware and experimental
- Cleaning results F_2/Ar/N_2
- 500 wafer run
- Waste gas data
- Summary and conclusions

PECVD Chamber Cleaning

- Currently used cleaning gases:

  Oxide / nitride films (PECVD): NF_3, CF_4, C_2F_6, C_3F_8

  Poly-Si CVD, MOCVD of W and TiN: NF_3

- CVD chambers need frequent cleaning of all process-relevant reactor surfaces to sustain particle- and defect free film deposition

Drivers for F_2-based Plasma-Cleaning

- Proposed gases: Low GWP* Gas Mixtures
- F_2 (GWP=0) as NF_3, PFCs (perfluorocarbon) alternative

	GWP	Life time			GWP	Life time
CF_4	7390	5000		NF_3	17200	740
CHF_3	11700	264		SF_6	22800	3200
CH_2F_2	650	5,6		c-C_4F_8	8700	3200
C_2F_6	12200	10000		C_4F_6	~0	~0
C_3F_8	7000	2600		c-C_5F_8	90	~1

*GWP (Global Warming Potential); CO_2 = reference = 1

Properties of F_2-based cleaning gas mixture

- F_2 diluted in N_2 and Ar (compressed gas)
- Transportable in standard gas cylinder
- Corrosive, **not inflammable, not explosive**
- A diluted F_2-gas mixture is best for an efficient chamber clean
- F_2 mixtures require a passivation of an existing stainless steel gas delivery system (one time procedure)

F_2 Gas Mixture – Gas Cabinet Example

- Gas mixture 1: $F_2/Ar/N_2$ → 13,56 MHz plasma
- Gas mixture 2: $F_2/Ar/N_2$ → 400 kHz RPS-unit

- Safety gas cabinet
- 3 way valve, purge gas N_2
- Gas cylinder: 10L, 100 bar

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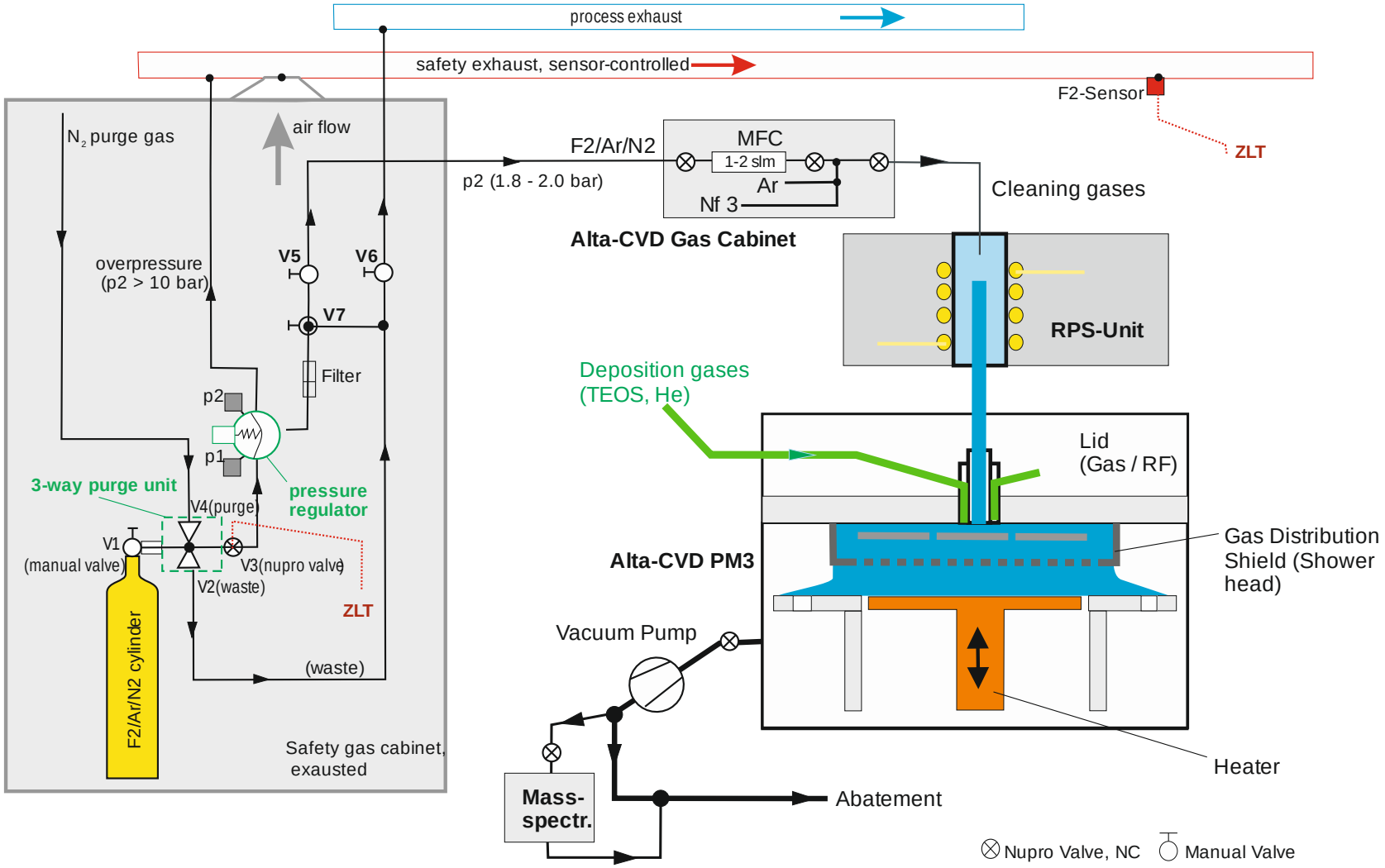
$F_2/Ar/N_2$ Gas Mixture – Facilitation Example



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CVD Tools at Fraunhofer EMFT (200mm)

- Alta-CVD , Brooks VX400

  PECVD for SiO_2 films - PETEOS, BPSG

  - 13,56 MHz plasma clean, C_2F_6 / NF_3 based

  - RPS (remote plasma source) clean, NF_3 based

- AMAT PECVD, P 5000

  PECVD for SiO_2 films, lamp-heated

  - 13,56 MHz plasma clean, C_2F_6 /NF_3 or CF_4 based

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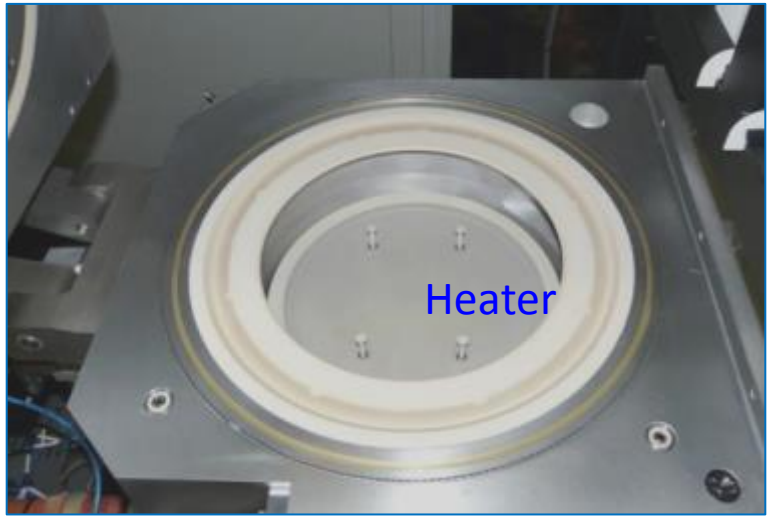
RPS Unit on Top of Alta-CVD Chamber



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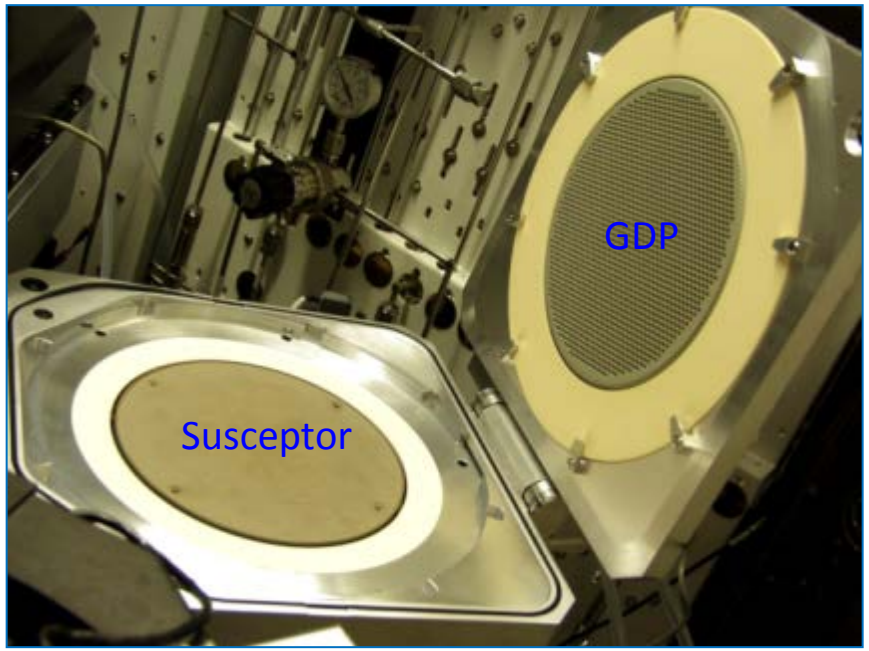
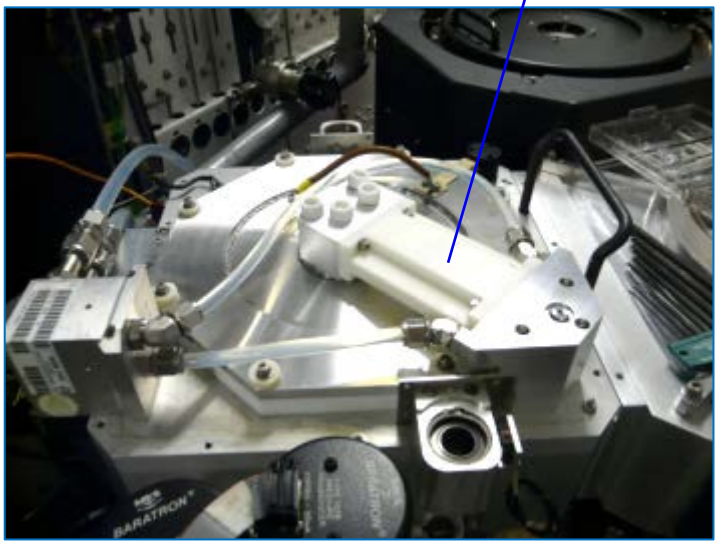
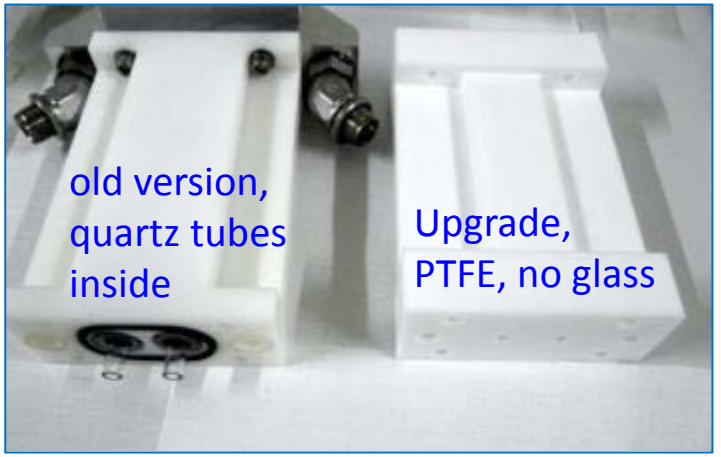
AMAT P5000 PECVD - Details







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SiO_2 Cleaning Rate – Experimental

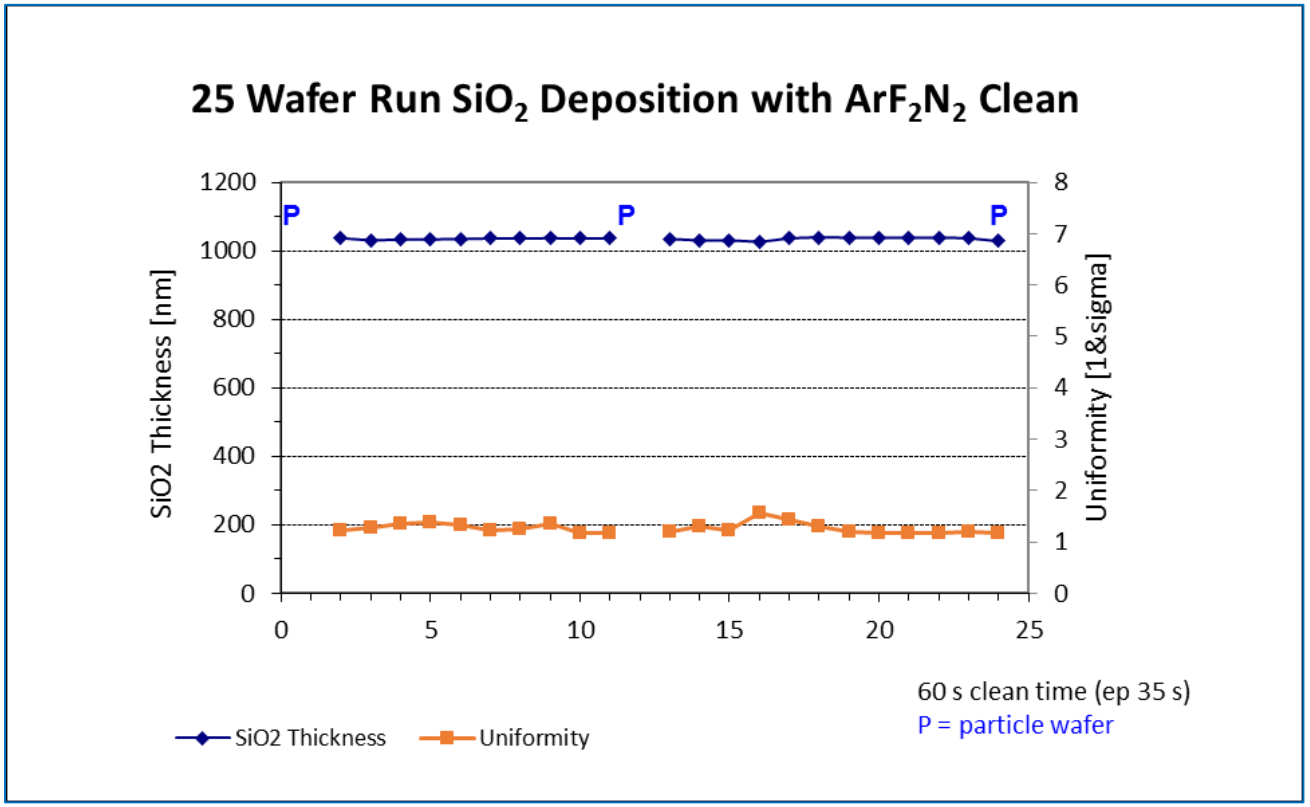
- Deposition of 2 µm PETEOS-film, 200mm Si-substrates
- Thickness measured with reflectometer / ellipsometer
- SiO_2-Etch rate calculated from post-etch TEOS film thickness
- Constant parameters:
  55 deg. C wall / lid temp., 400 deg. C heater temperature
- Parameter Variations:
  Gas flows, chamber pressure, RF-power, Spacing
- 30% higher SiO_2 cleaning rate compared to C_2F_6

13,56 MHz Plasma Cleaning Process (2)

- Repeatability of SiO_2 deposition, 3 x 25 wafer

Run #	# of adders (particle size ≥ 0,25µm)			
	Slot 1	Slot 12	Slot 25	Average
1	38	7	21	22
2	5	5	32	14
3	11	2	6	6
Mean	18	5	20	**14**

AMAT P5000
lamp-heated
CVD, 200mm



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13,56 MHz Plasma Cleaning Process (4)

Amount of cleaning gas needed for 25 Wafer Lot (1µm SiO2 depo / wafer):

C2F6/O2:	tot. flow/wafer [slm]	tot. flow /lot [slm]	**tot. gas/lot** [g]	F2/lot [g]
C2F6-Flow	0,9	21,6	**132,7**	**114,4**
O2-Flow	0,9	22,2	31,7	
NF3-Flow	0,1	1,9	5,9	
Mean SiO2-rate	~1100nm/min			

CF4/O2:	tot. flow/wafer [slm]	tot. flow /lot [slm]	**tot. gas/lot** [g]	F2/lot [g]
CF4-Flow	0,8	19,3	**75,7**	**65,3**
N2O-Flow	0,3	7,0	18,8	
Mean SiO2-rate	~1200nm/min			

F2/Ar/N2:	tot. flow/wafer [slm]	tot. flow /lot [slm]	tot. gas/lot [g]	**F2/lot** [g]
F2/Ar/N2-Flow	0,8	19,5	27,1	**6,6**
Mean SiO2-rate	~1500nm/min			

Ratio C2F6 : F2	**17 : 1**
Ratio CF4 : F2	**10 : 1**

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13,56 MHz Plasma Cleaning Process (5)

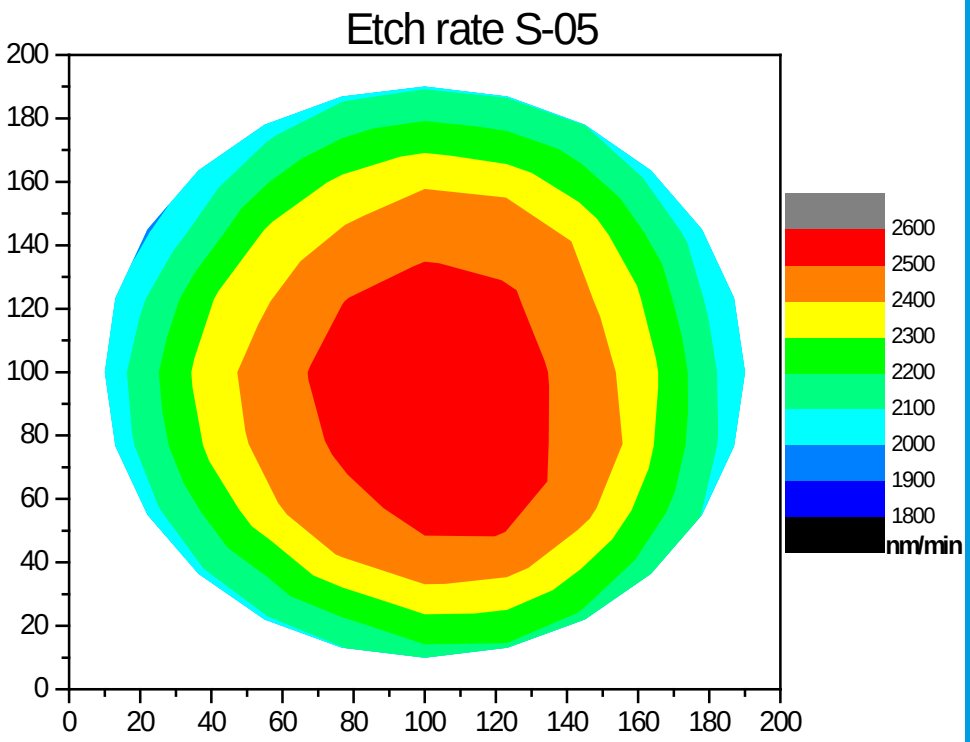
Bond Dissociation energies			
Molecule			Diss. Energy
			[kJ/mol @ 298K]
N_2	-->	N + N	945
F_2	-->	F + F	155
NF_3	-->	NF_2 +F	243
NF_2	-->	NF + F	318
NF	-->	N + F	301
NF_3	-->	N + F +F + F	862
CF_4	-->	CF_3 + F	506
C_2	-->	C + C	607
O_2	-->	O + O	498
N_2O	-->	NO + N	115
source:	united states department of commerce,		
	national bureau od standards, Lewis M. Branscomb		

400 kHz RPS Cleaning Process

- Gas mixture 2
- Monitored: SiO_2-deposition rate, particles in SiO_2-film25-wafer runs in auto-mode
- 500 wafers deposited, clean after every wafer
- Optical inspection of process kit parts
- F_2 gas mixture has identical cleaning rates of SiO_2 ≥ 1,0 µm/min compared to a BKM NF_3-based recipe
- Drop-In recipe to substitute Ar/NF_3 chemistry (same pressure, total flow, spacing, step times)
- Potential for optimization still given
- Cleaning efficiency of F_2 gas mixture ≥ factor 1,2 compared to NF_3

400 kHz RPS Cleaning Process (2)

- 4 Step process:
  - Ar-Flow and Ignition
  - F_2-addition to Ar
  - Inner clean
  - Outer clean
- Etch behavior: Center fast



SiO_2-etch rate of complete NF_3-cleaning recipe with RPS-Unit

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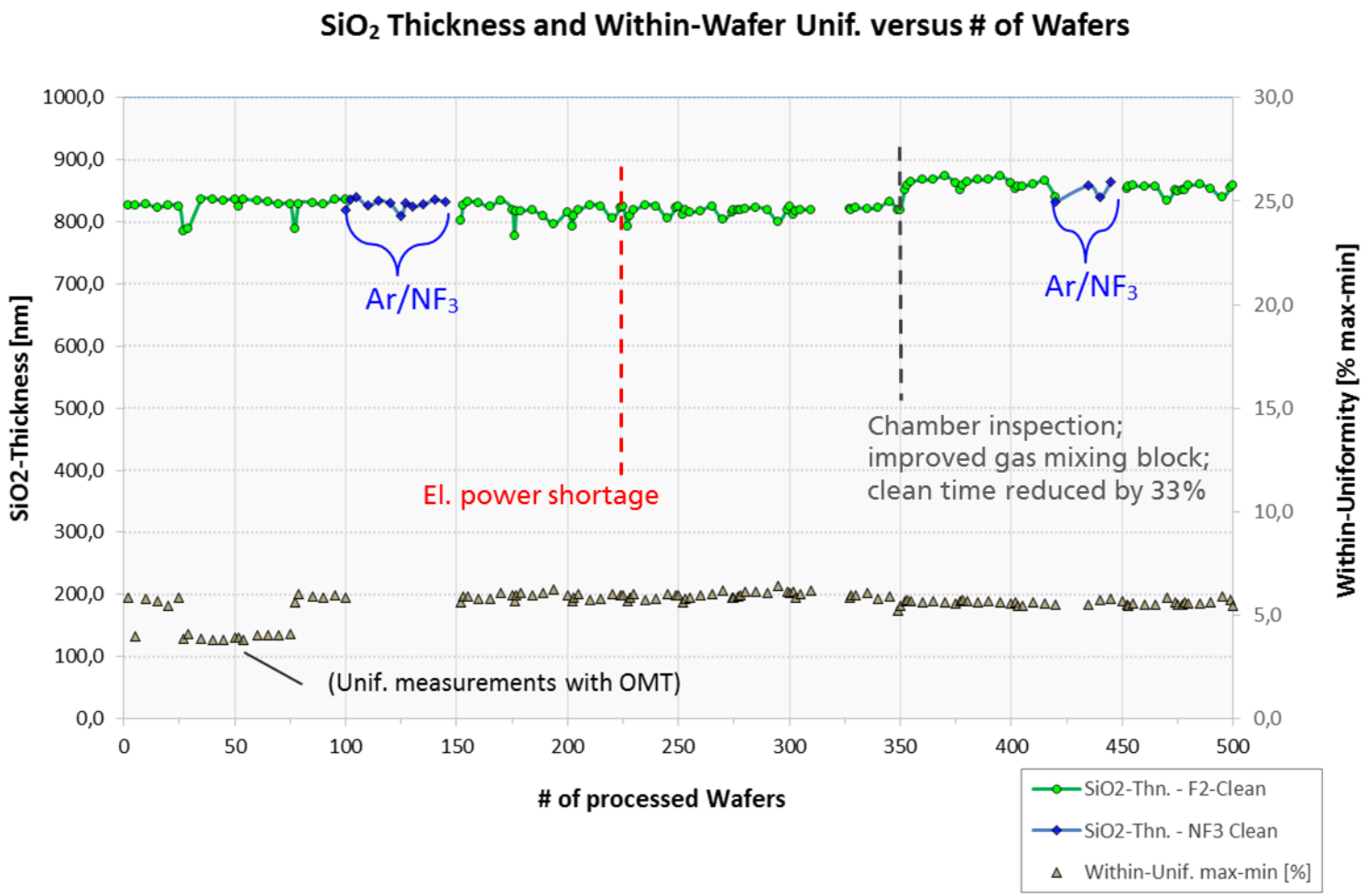
400 kHz RPS – 500 Wafer Run - Results (2)



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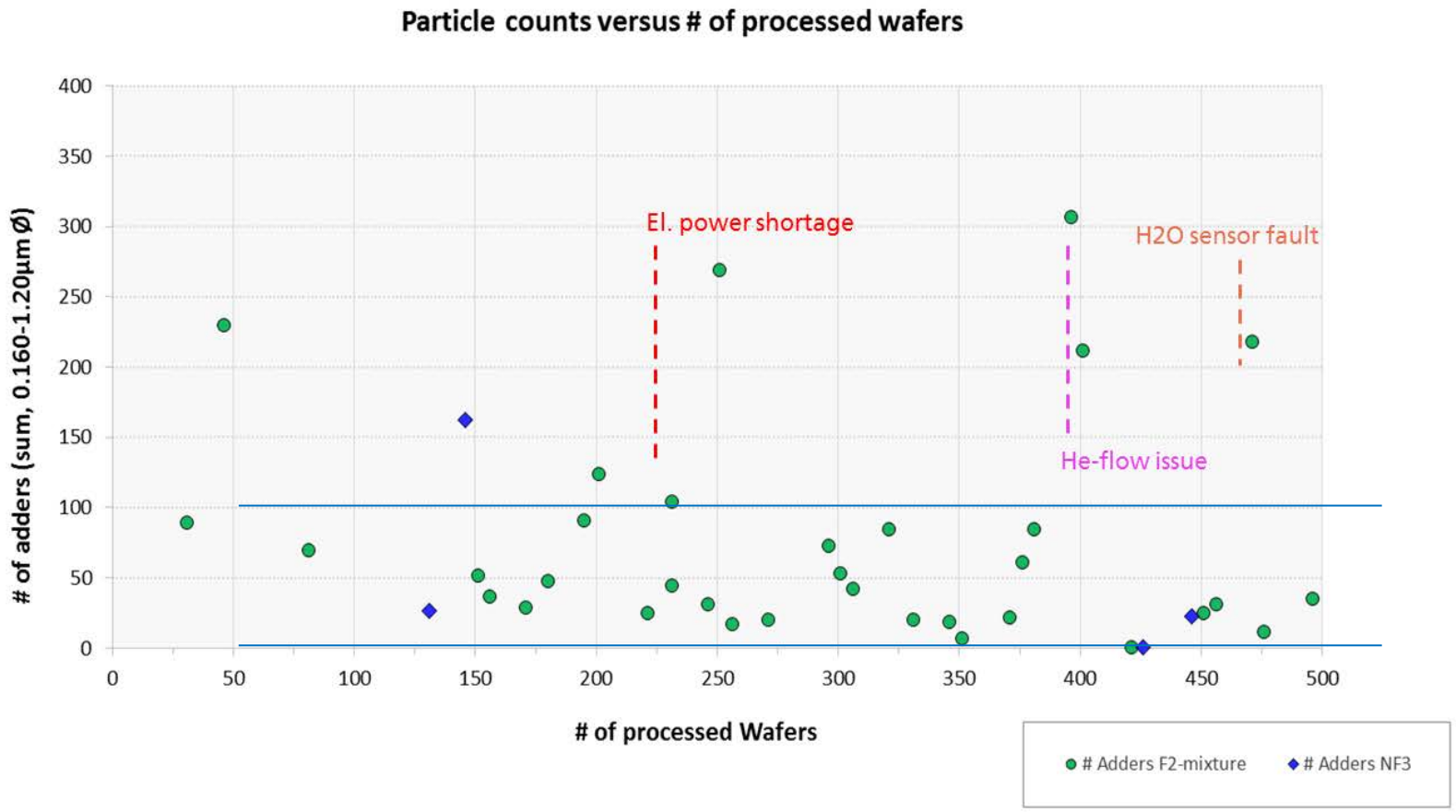
400 kHz RPS – 500 Wafer Run - Results (3)



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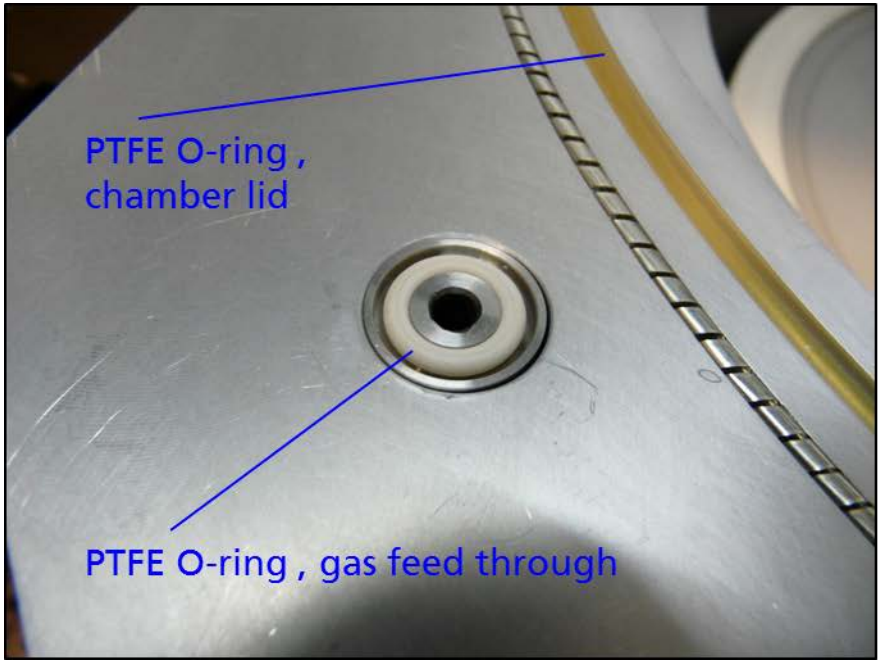
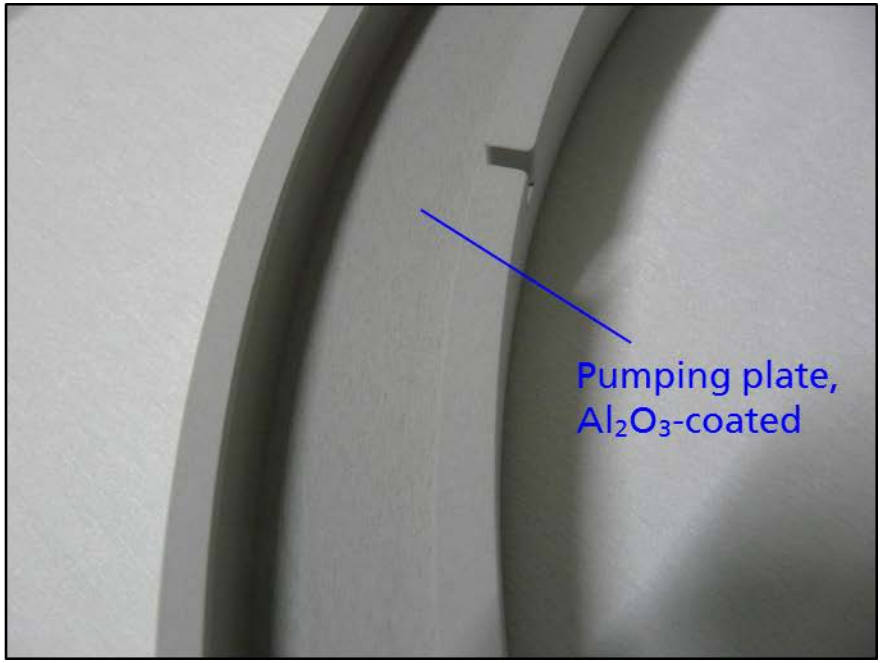
400 kHz RPS – 500 Wafer Run - Results (5)

- Optical inspection showed no noticeable effects of the cleaning plasma on process kit parts
- PTFE O-rings fully intact, no signs of wear after 500 processed wafers





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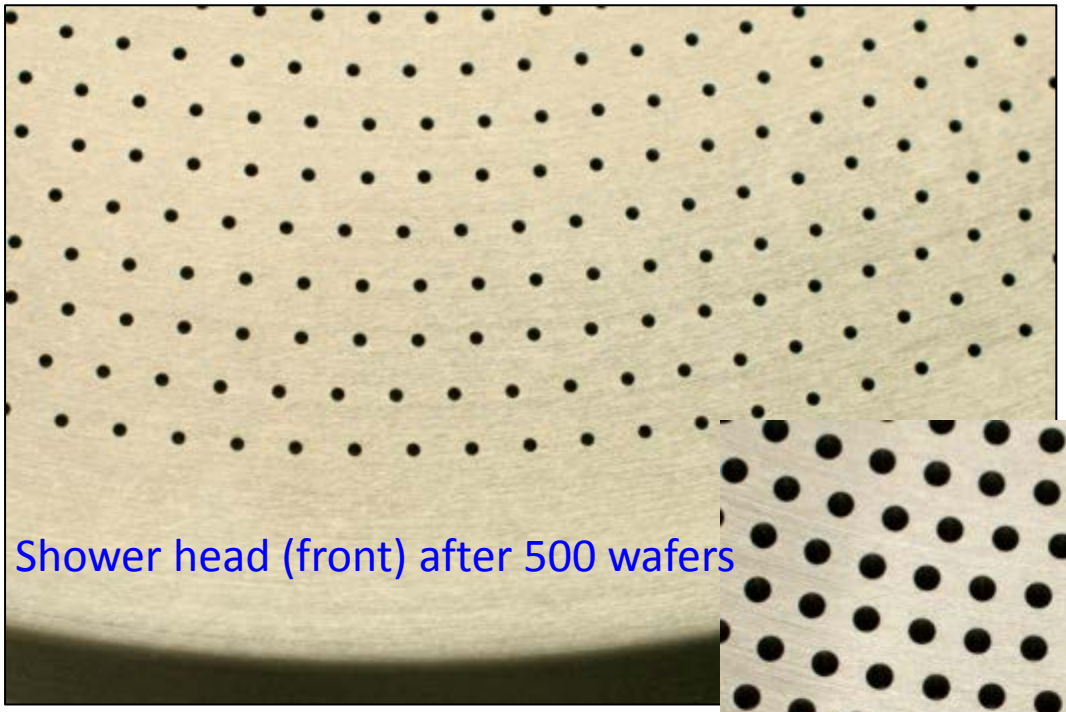
400 kHz RPS – 500 Wafer Run - Results (6)



Shower head (front) after 500 wafers

Shower head (backside) after 500 wafers

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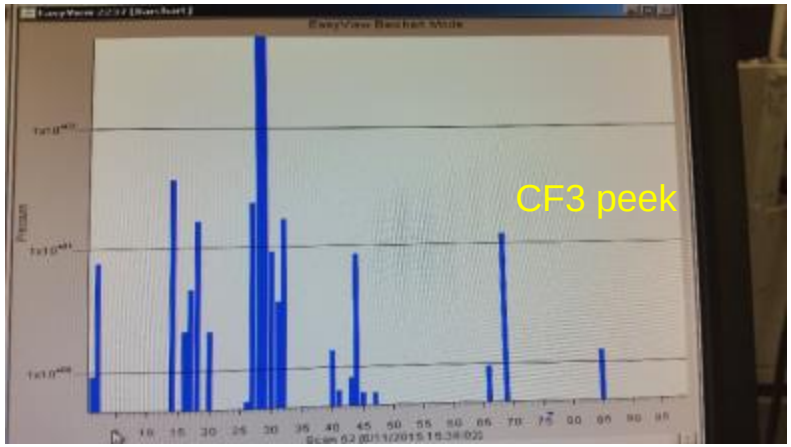
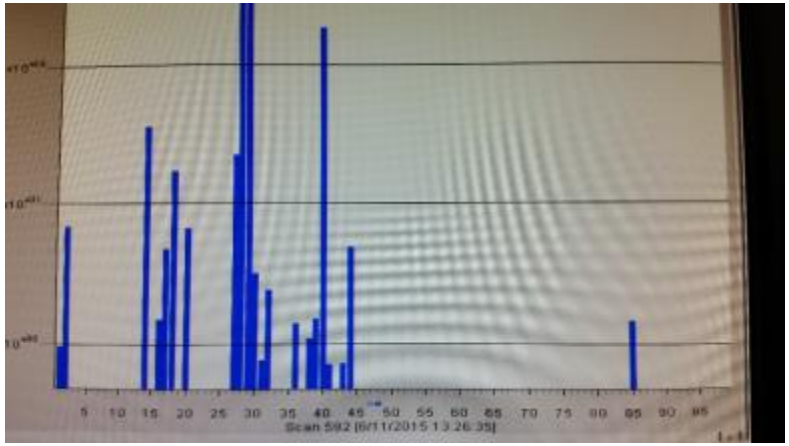
Waste Gas Analysis

- Atmospheric mass spectrometer was mounted behind process pump exhaust
- In case of C_2F_6 compared to F_2-mixture, the absence of the big CF_3 peek confirms our early estimation of a cleaning efficiency factor >17 for F_2-mixture compared to C_2F_6

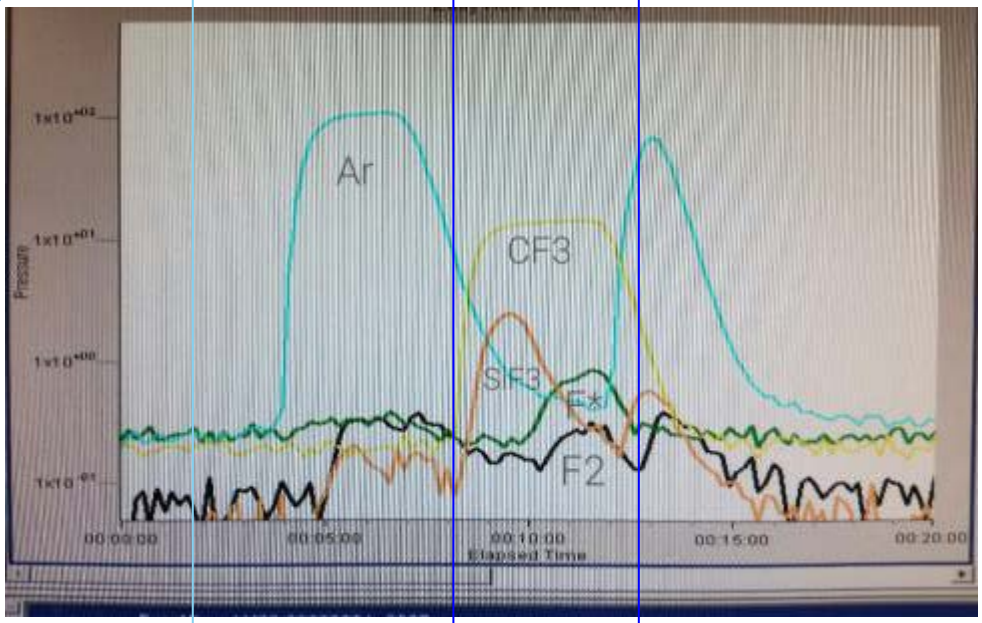
Waste Gas Analysis (2)

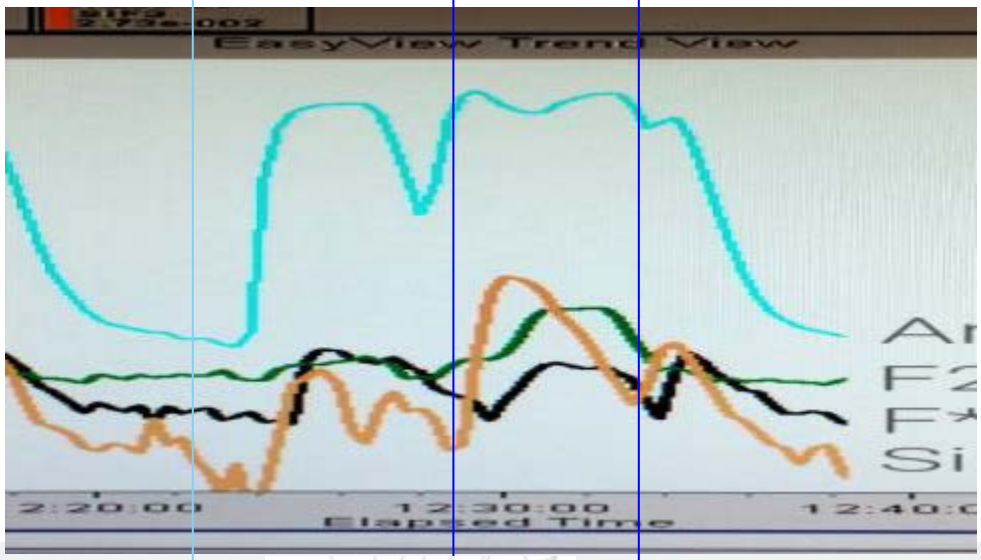


C_2F_6 Clean, 13,56 MHz parallel-plate



F_2 - gas mixture 2, 440kHz RPS





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Summary and Conclusions

- Higher cleaning efficiency for F_2 gas mixtures
- F_2 gas mixtures showed similar performance for particle density and process kit degradation compared to NF_3 / PFCs
- Extended life time of process kit parts expected, especially for processes using PFCs as cleaning gases (no CF_3 radicals)
- Environmental-friendly processing
- Drop-in processes for NF_3, C_2F_6 and CF_4

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