

Green ICT – Plasma process alternatives to substitute PFCs, SF₆ and NF₃

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Green ICT – Plasma process alternatives to substitute PFCs, SF₆ and NF₃

1. Intro and Motivation
2. Green ICT – Project Topics
3. Environmental Aspects
4. Fluorine Gas Mixture (FAN)
5. PECVD – FAN-Gas Cleaning
6. DRIE – FAN-Gas Etching / Abatement
7. Summary and Conclusions

Green ICT – Plasma process alternatives to substitute PFCs, SF₆ and NF₃

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5. PECVD – FAN-Gas Cleaning

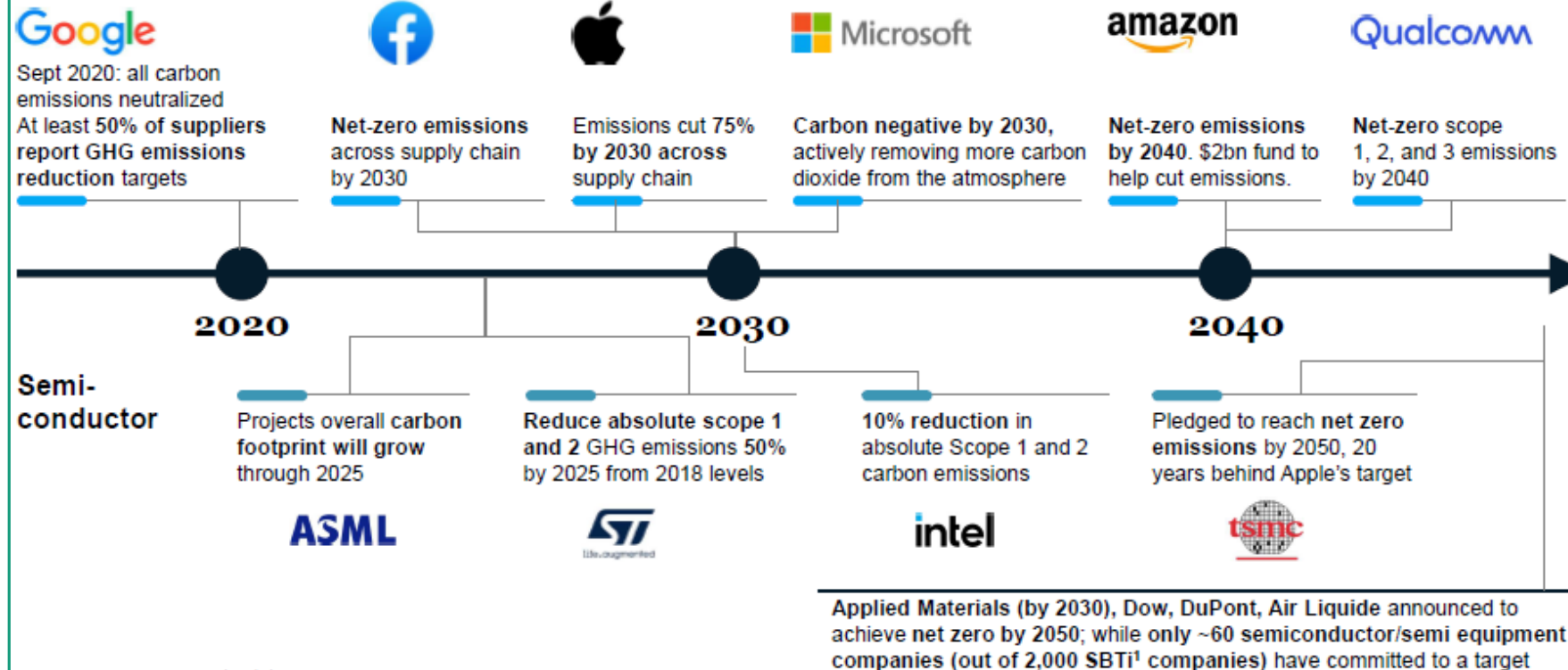
6. DRIE – FAN-Gas Etching / Abatement

7. Summary and Conclusions

Green ICT - Motivation

2. Customer commitments towards net-zero are very aggressive relative to semi player goals, presenting a new challenge

Downstream tech players



1. SBTi: Science Based Targets Initiative

Source: Corporate reports; Corporate websites; Press search; SBTi

McKinsey & Company

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McKinsey
& Company

Future of the US semiconductor ecosystem

Discussion document
May 5, 2022

presented by
McKinsey & Company
at 2022 ASMC

Green ICT - Motivation

Commitments towards net-zero carbon emissions differ noticeably:

Downstream tech players: 2030, the latest 2040

Semiconductor fabs: 10% reduction by 2030 (?)

Equipment vendors: 2030 – 2050 (only 60 out of 2000 companies have committed to a target)

Green ICT – Project Topics

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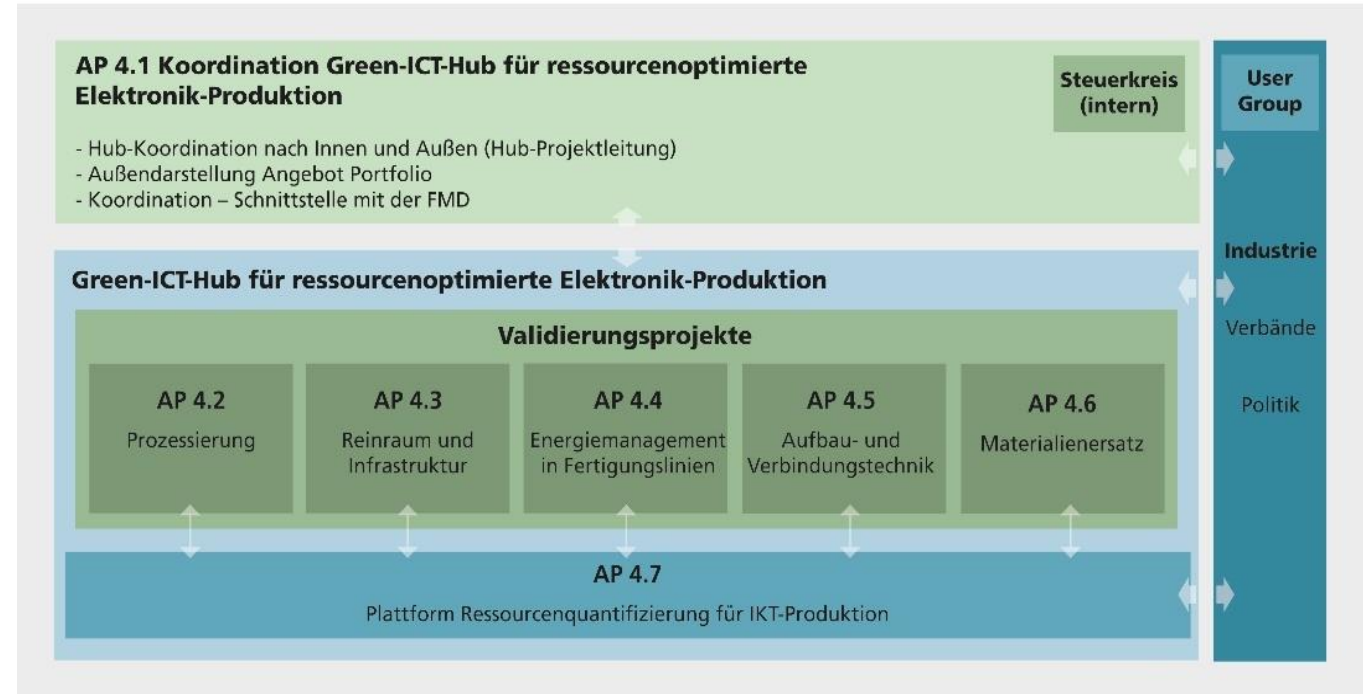
5. PECVD – FAN-Gas Cleaning

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7. Summary and Conclusions

Green ICT - Project Topics

- Hub Coordination
- Processing
- Cleanroom and Infrastructure
- Energy Management
- AVT (packaging)
- Material Substitution
- Resource Quantification



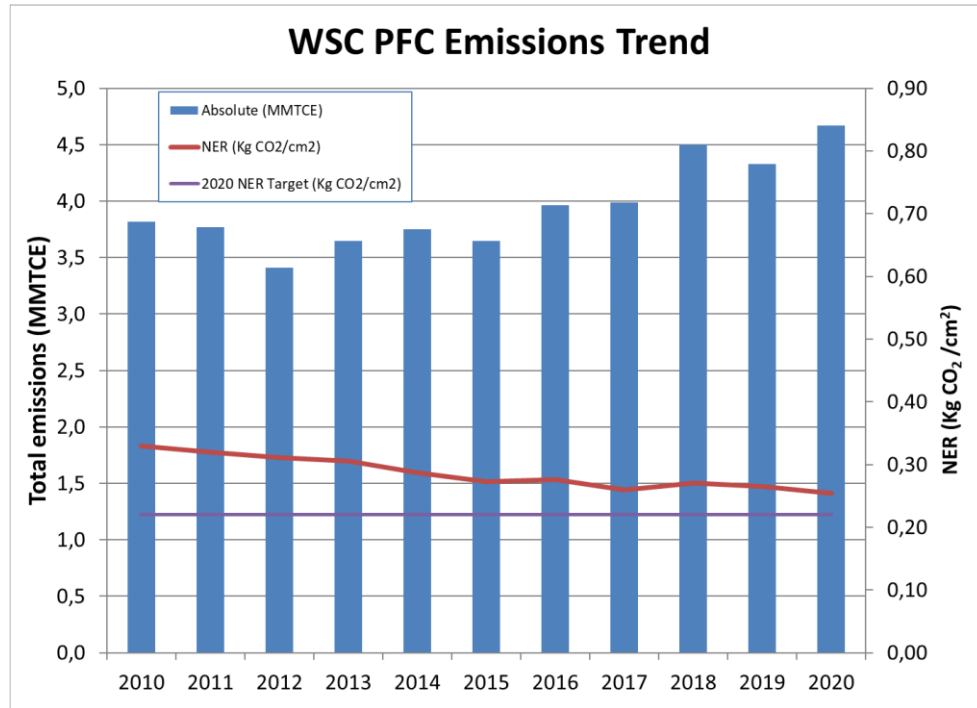
Green ICT - Project Topics

- Processing 10-50% reduction – always measured in CO₂-equivalents
- Cleanroom and infrastructure 30% reduction (based on 2019 energy mix in Germany)
- Energy management 10% reduction (based on 2019 energy mix in Germany)
- AVT (packaging) 15% reduction
- Material substitution new substances (gases, liquids, substrates etc.)

Green ICT – Environmental Aspects

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Green ICT – Environmental Aspects



NER (kg CO₂/cm²) not yet reached

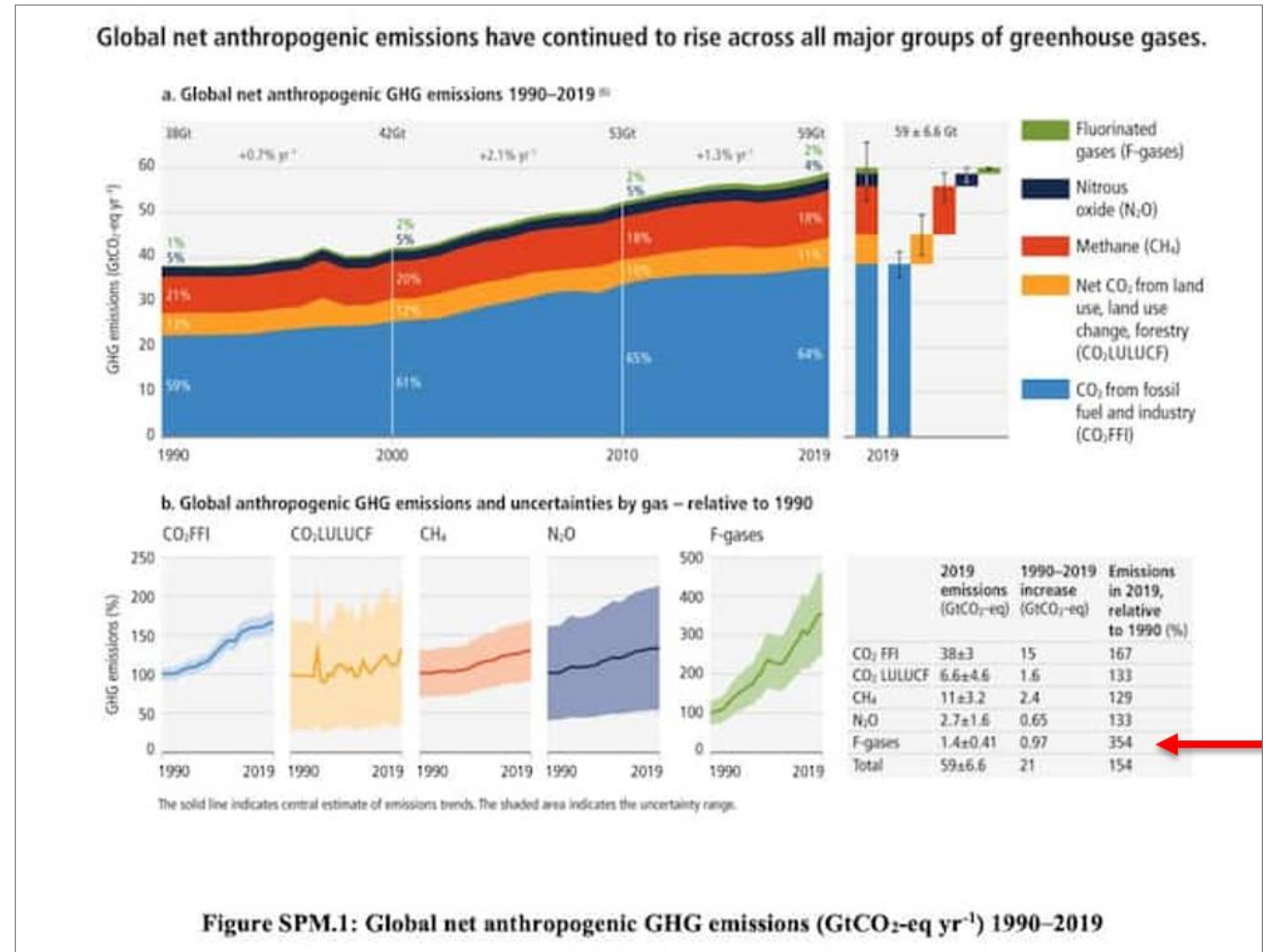
Gas	GWP	Lifetime
	[CO ₂ eq]	[years]
CF ₄	7390	5000
CHF ₃	11700	264
CH ₂ F ₂	650	5,6
C ₂ F ₆	12200	10000
C ₃ F ₈	7000	2600
c-C ₄ F ₈	8700	3200
SF ₆	22800	3200
NF ₃	17200	740
C ₄ F ₆	~0	~0
c-C ₅ F ₈	90	~1
F ₂ (FAN)	~0	~0

GWP = Global Warming Potential
(values normalized for 100 year lifetime)

Source: WSC (World Semiconductor Council), "joint statement of the 25th) meeting of the WSC, June 2nd, 2021, virtual"

Green ICT – Environmental Aspects

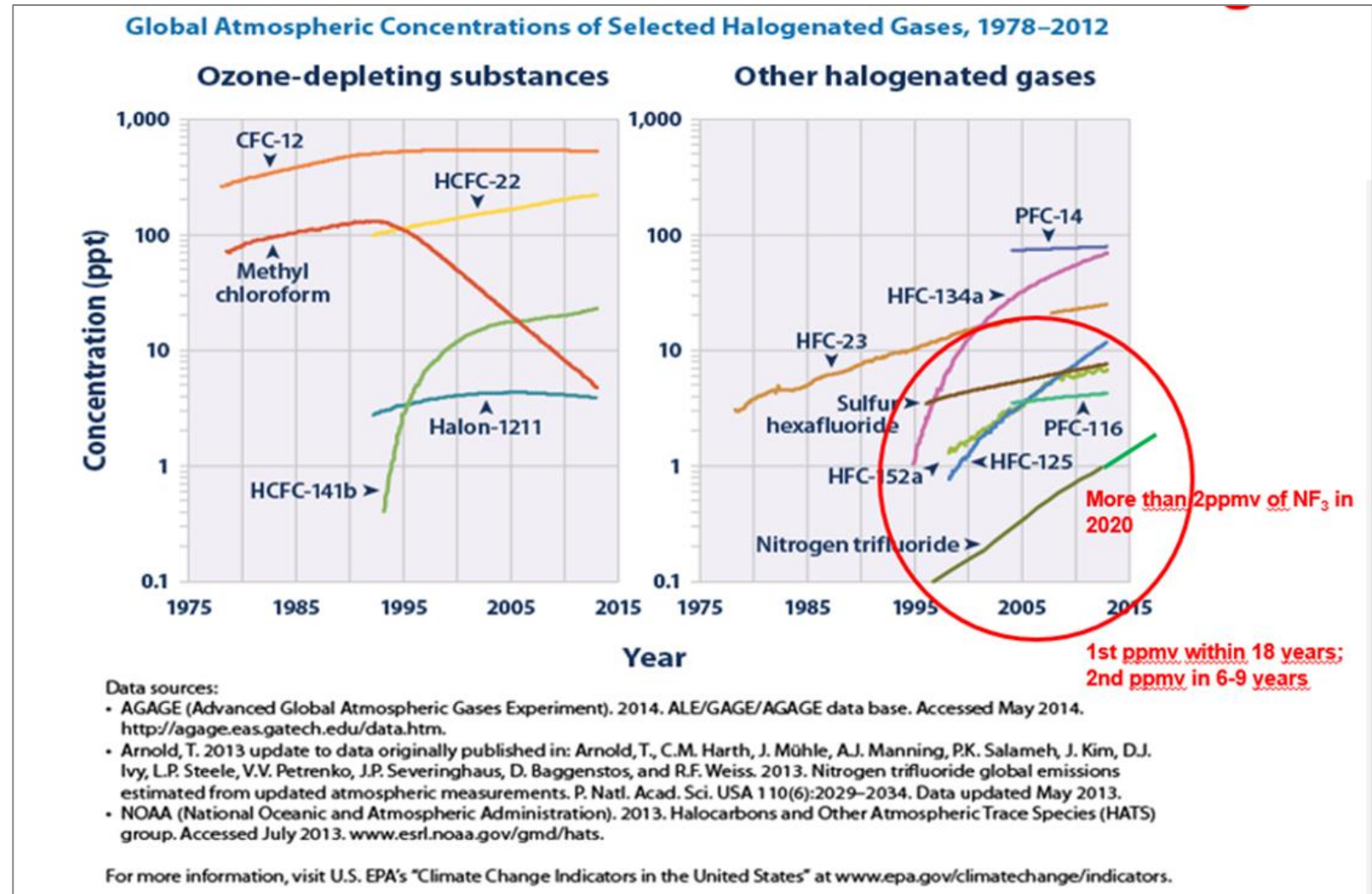
- Highest slope 1990 - 2019: F-gases
- F-gases (NF_3 , SF_6 , C_4F_8 ,...) are mainly used in the semiconductor industry



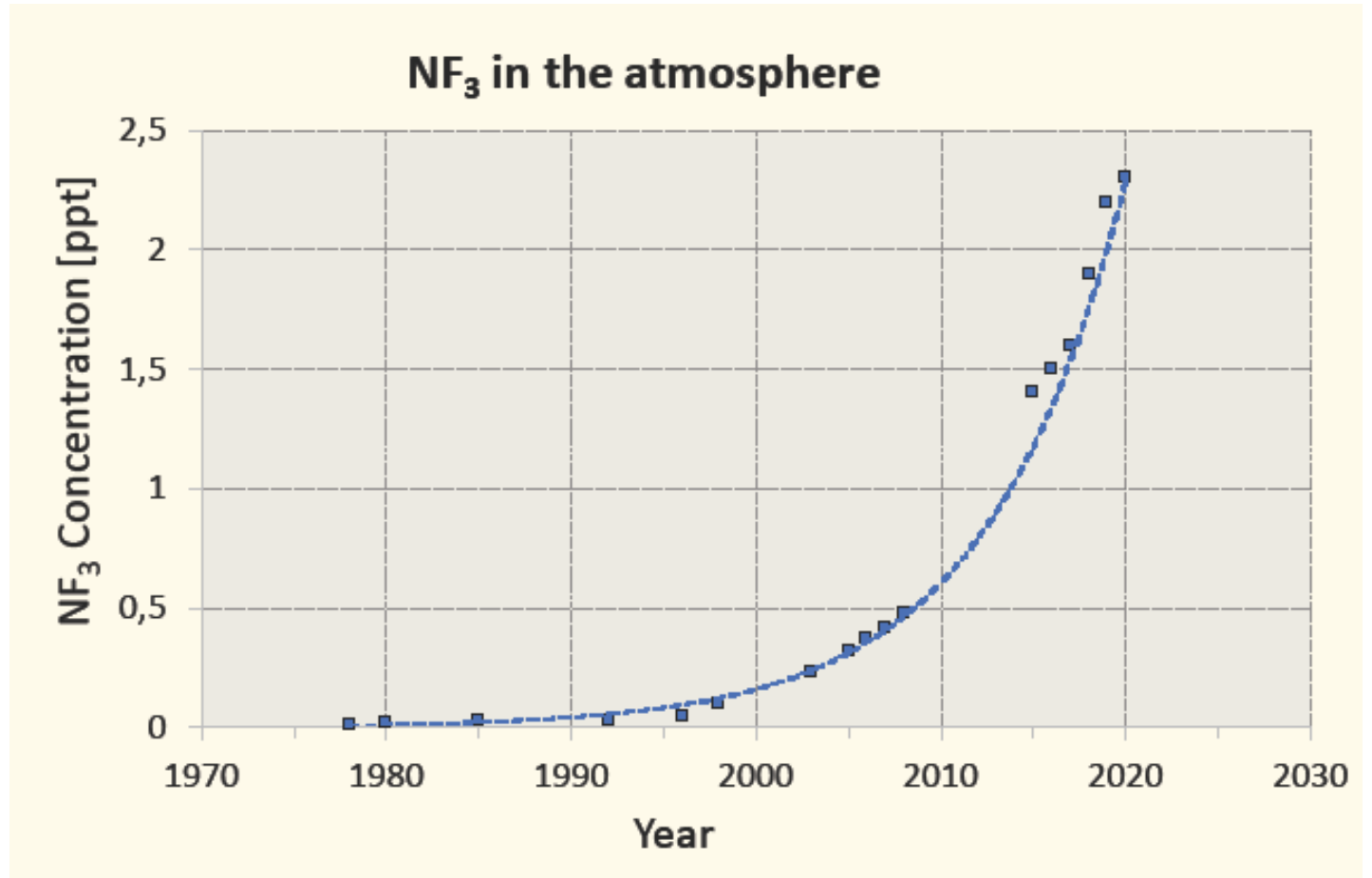
Green ICT – Environmental Aspects

- Activities to limit/avoid certain gases occurred after 100 ppt was surpassed (for example Halon-1211)

- NF_3 is soon reaching the “critical level”



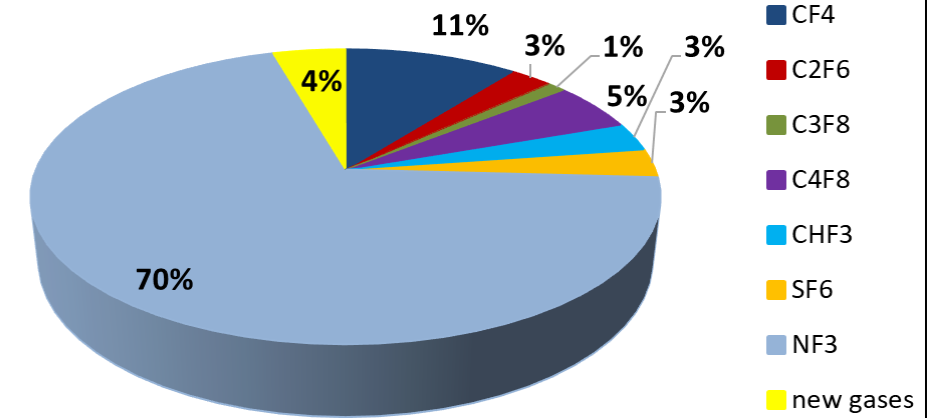
Green ICT – Environmental Aspects



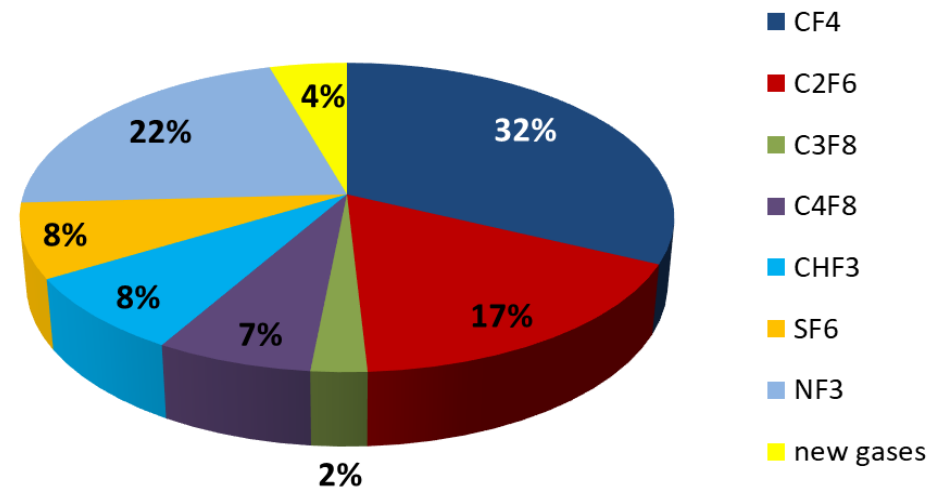
Green ICT – Environmental Aspects

- SF_6 : 3% consumption, 8% emissions
- NF_3 : 70% consumption, 22% emissions
- New gases:
 C_4F_6 , CH_2F_2 , C_5F_8 , $\text{C}_4\text{F}_8\text{O}$

2020 WSC PFC Consumption Data = 23.2 MKg



2020 WSC PFC Emissions = 4.7 MMTCE



Source: WSC, "joint statement of the 25th meeting of the WSC, June 2nd, 2021, virtual"

Green ICT – Environmental Aspects

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Green ICT – Fluorine Gas Mixture (FAN)

- C_4F_6 = etching gas with ~0 GWP
- **FAN** gas = **F**luorine / **A**rgon / **N**itrogen mixture, can be used for etching and cleaning
- F_2 is diluted in Ar and N_2 (compressed gas)
- Corrosive, not inflammable, not explosive
- F_2 -mixtures require passivation of existing stainless steel gas delivery system (one time)

Gas	GWP	Lifetime
	[CO ₂ eq]	[years]
CF ₄	7390	5000
CHF ₃	11700	264
CH ₂ F ₂	650	5,6
C ₂ F ₆	12200	10000
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c-C ₄ F ₈	8700	3200
SF ₆	22800	3200
NF ₃	17200	740
C ₄ F ₆	~0	~0
c-C ₅ F ₈	90	~1
F ₂ (FAN)	~0	~0

Green ICT – Fluorine Gas Mixture (FAN)

FAN mixture = efficient cleaning for PECVD

- Two qualified FAN-gas mixtures available:

“Solvaclean™ N” → RPS-based clean

“Solvaclean™ NO” → in-situ clean (less Ar, more N₂)

“Solvaclean™ N” and “Solvaclean™ NO” are trademarks of the Solvay AG

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 F ₆	-->	CF ₃ + CF ₃	402
CF ₃	-->	CF ₂ + F	469
CF ₂	-->	CF + F	194
CF	-->	C + F	485 (536)
O ₂	-->	O + O	498
N ₂ O	-->	NO + N	115

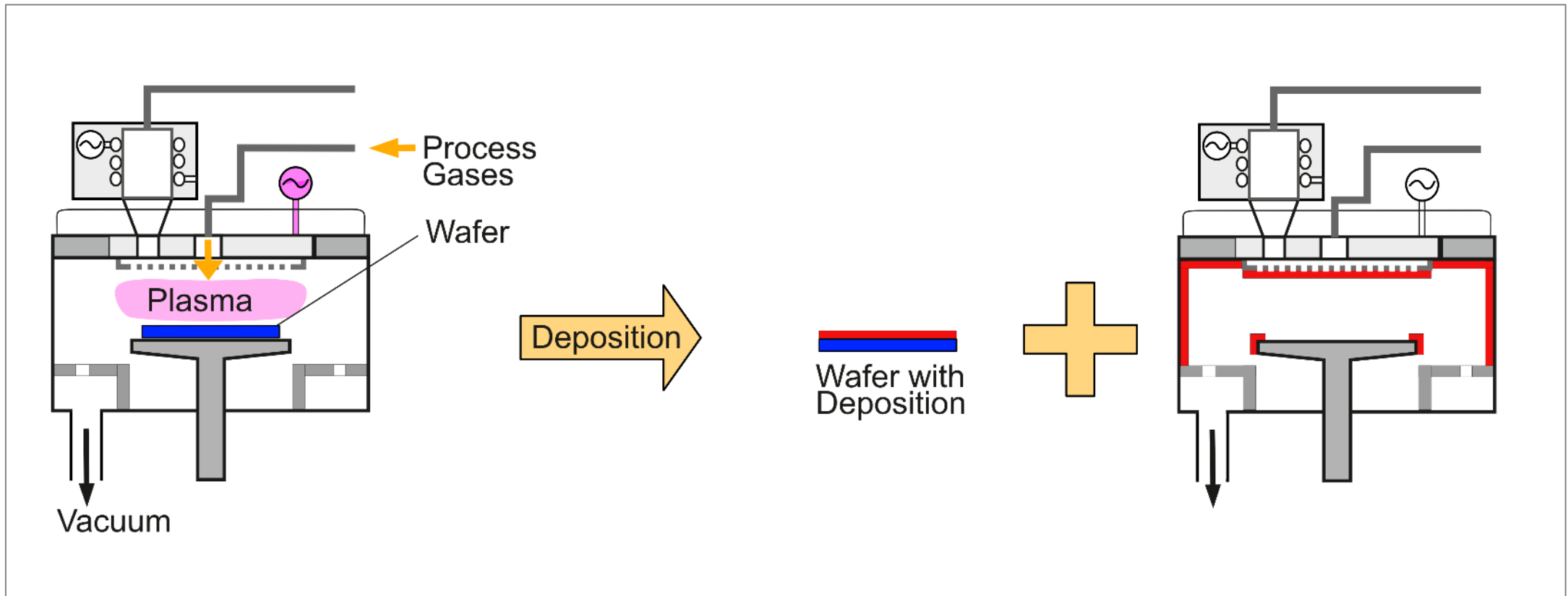
source: united states department of commerce,
national bureau of standards, Lewis M. Branscomb

Green ICT – FAN Gas Cleaning

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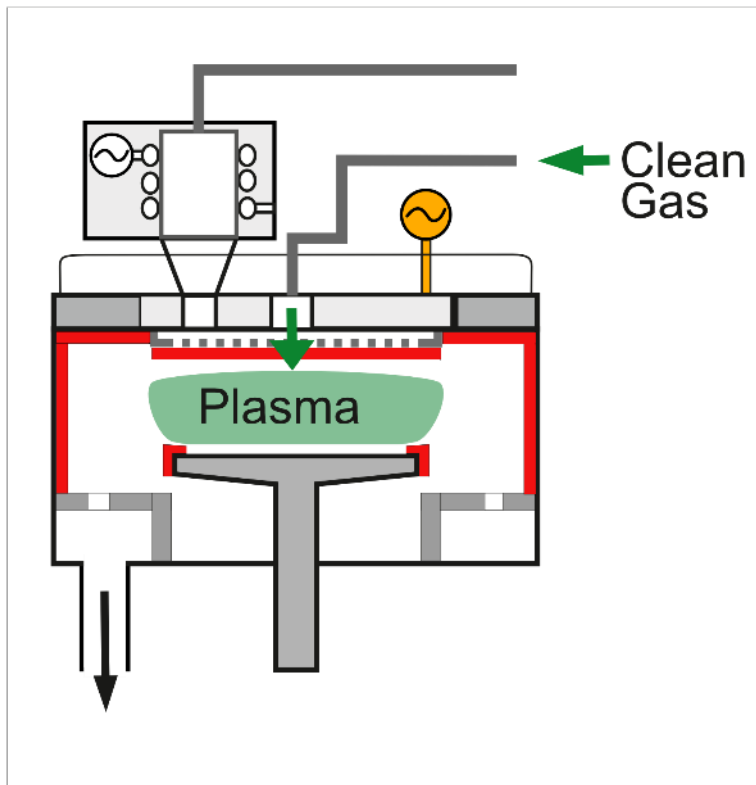
PECVD Part 1: Deposition of dielectric or Si-film on wafer



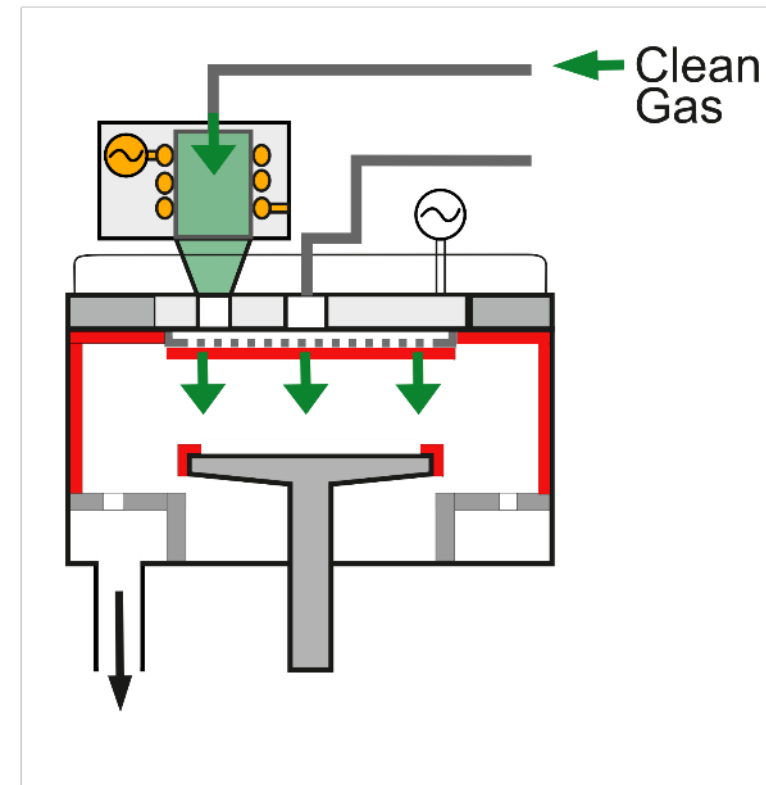
Green ICT – FAN Gas Cleaning

PECVD Part 2: Plasma-Cleaning of chamber

In-situ clean



RPS clean
(remote plasma
source)



Green ICT – FAN Gas Cleaning

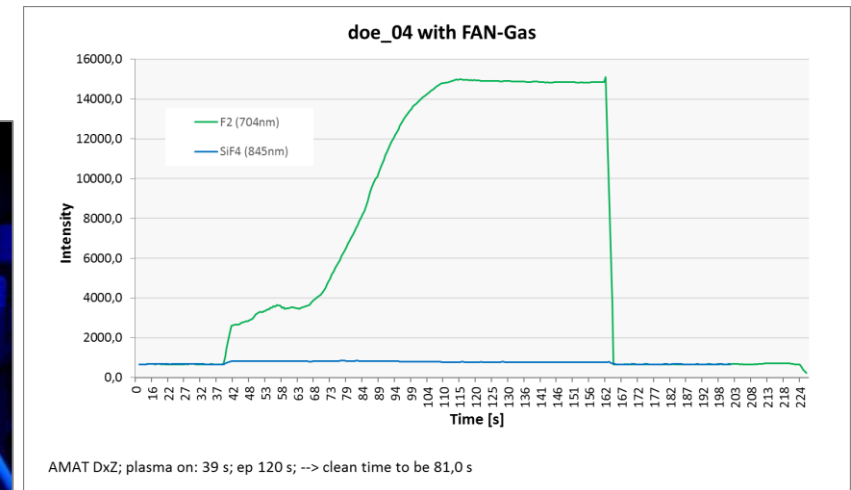
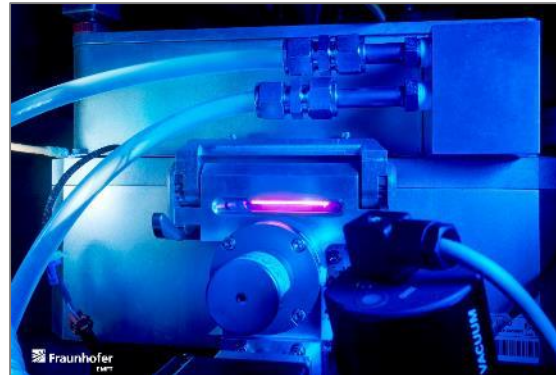
Comparison of currently used RPS-cleaning versus in-situ cleaning for PECVD-Tools

	RPS-based	In-situ
Type of Clean:	"Soft Cleaning"	" Hard Cleaning"
Typical Chemistry:	Ar + NF ₃	C ₂ F ₆ , C ₄ F ₈ , SF ₆ + O ₂ (PFCs)
Species in chamber:	only radicals	ions + radicals
Endpoint detection:	mostly optical (F-line)	optical (F-line)
	downstream extra plasma	viewglass into chamber
Process Kit Lifetime:	Superior	high wear of parts
Efficiency:	Efficient use of NF ₃	inefficient F-usage
Typical Tool vendors:	AMAT, Yusum, Novellus, SPTS(?),...	AMAT, Novellus, SPTS, PT, Evatec, Alta-CVD,...

Green ICT – FAN Gas Cleaning (In-situ)

13,56 MHz Plasma Cleaning – Typical Recipe

- Same SiO_2 cleaning rate compared to $\text{C}_2\text{F}_6 / \text{O}_2$
- “SolvaClean NO”, 30% F_2 / low Ar-content
- Single wafer tool:
~800 sccm FAN, 300sccm O_2
- Batch Tool:
~2500 sccm FAN, 500sccm O_2

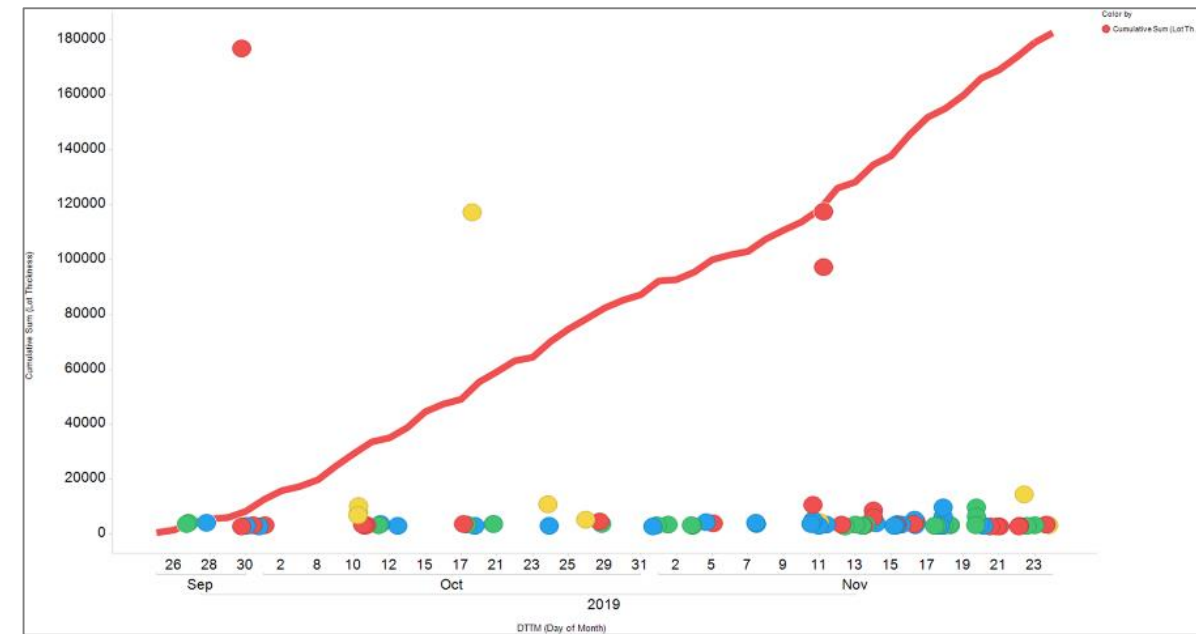


Green ICT – FAN Gas Cleaning (In-situ)

F-Consumption and Particle Performance (customer data)

- Novellus Sequel Concept 2, PECVD of SiO₂
- 25.000 wafers processed (200mm wafer)
- FAN versus C₂F₆/O₂

Cleaning chemistry			Solvaclean [®] NO	POR (C ₂ F ₆ / O ₂)	Solvaclean [®] NO	POR (C ₂ F ₆ / O ₂)
F ₂ -Gas used			weight	weight C ₂ F ₆ Gas	F ₂ content	F ₂ in C ₂ F ₆
1 µm SiO ₂ onto 25 wafers:			96,0 g	327,1 g	34,0 g	270,2 g
onto 15.000 wafers:			57,6 kg	196,2 kg	20,4 kg	162,1 kg
10 cylinders of FAN "NO":					22,0 kg	
			Gas weight factor: 3,4		Factor for F ₂ : 8,0	



25.000 wafer processed; red curve = # of wafer cumulation
Coloured Dots = particle values

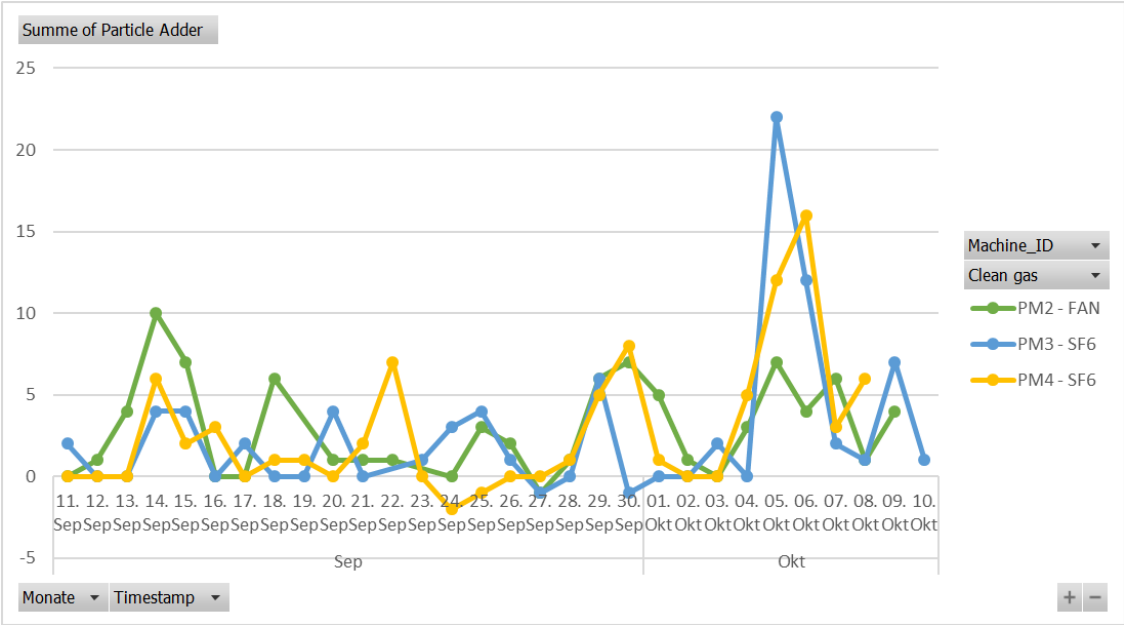
Source: "Ecofluor" Final Report, BMBF 2017

Green ICT – FAN Gas Cleaning (In-situ)

F-Consumption and Particle Performance (customer data)

- PECVD of SiO₂
- 10.000 wafers processed (150mm wafer)
- FAN versus SF₆/N₂O

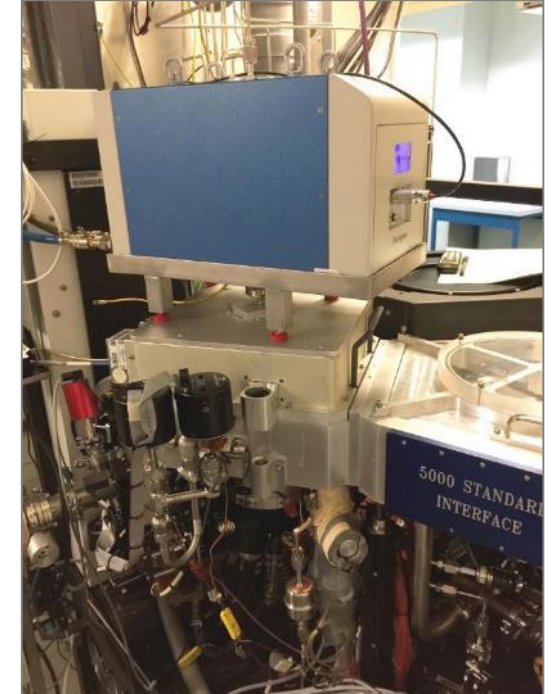
Cleaning chemistry F ₂ -Gas used	Solvaclean [®] NO / N ₂ O	POR (SF ₆ / N ₂ O)	Solvaclean [®] NO	POR (SF ₆ / N ₂ O)
	weight	weight SF ₆ Gas	F ₂ content	F ₂ in SF ₆
3 µm SiO ₂ onto 5 wafers:	17,1 g	34,4 g	6,0 g	26,9 g
onto 10.000 wafers:	34,1 kg	68,8 kg	12,1 kg	53,7 kg
5 cylinders of FAN "NO":			11,0 kg	
	Gas weight factor: 2,0		Factor for F ₂ : 4,4	



Green ICT – FAN Gas Cleaning (RPS)

RPS Plasma Cleaning – Typical Recipe

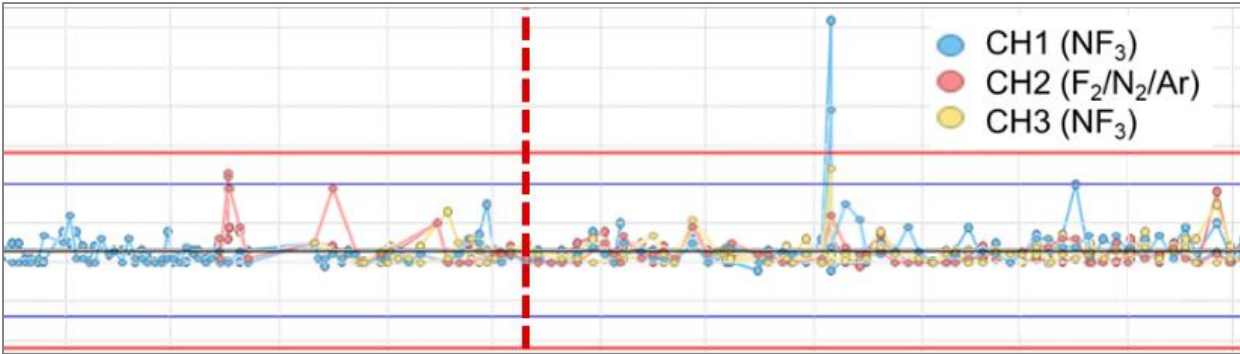
- Higher or same SiO_2 cleaning rate compared to Ar / NF_3
- “SolvaClean N”, 30% F_2 / higher Ar-content
MKS 400kHz RPS systems have limit for ignition with N_2
- Single wafer tool:
~1600 sccm FAN



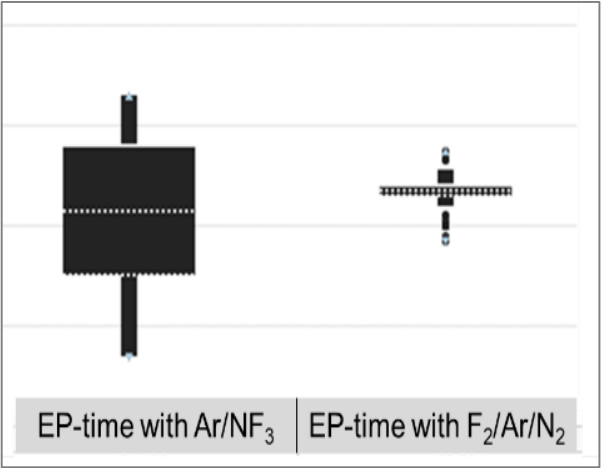
Green ICT – FAN Gas Cleaning (RPS)

F-Consumption and Particle Performance (customer data)

- AMAT Producer, PECVD of Si₃N₄
- 72.000 wafers processed (200mm wafer)
- FAN versus Ar/NF₃



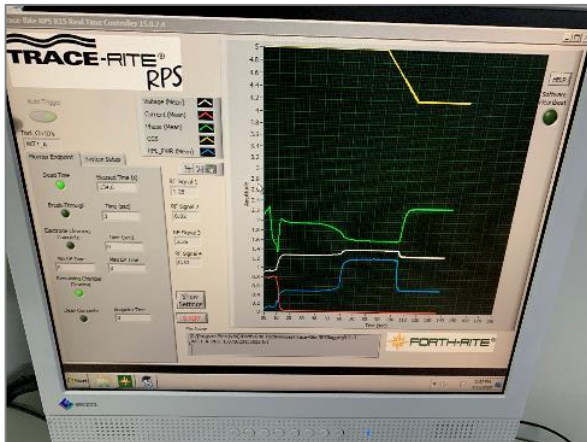
F ₂ -Gas used	Cleaning chemistry	Solvaclean [®] N	POR (Ar / NF ₃)	Solvaclean [®] N	POR (Ar / NF ₃)
		weight	weight NF ₃ Gas	F ₂ content	F ₂ in NF ₃
	1 µm SiO ₂ onto 2 wafers:	7,9 g	7,8 g	2,8 g	4,2 g
	onto 70.000 wafers:	138,0 kg	136,5 kg	49,0 kg	73,5 kg
		Gas weight factor: 1,0		Factor for F ₂ : 1,5	



Green ICT – FAN Gas Cleaning (RPS)

RPS Plasma Cleaning – New Microwave RPS

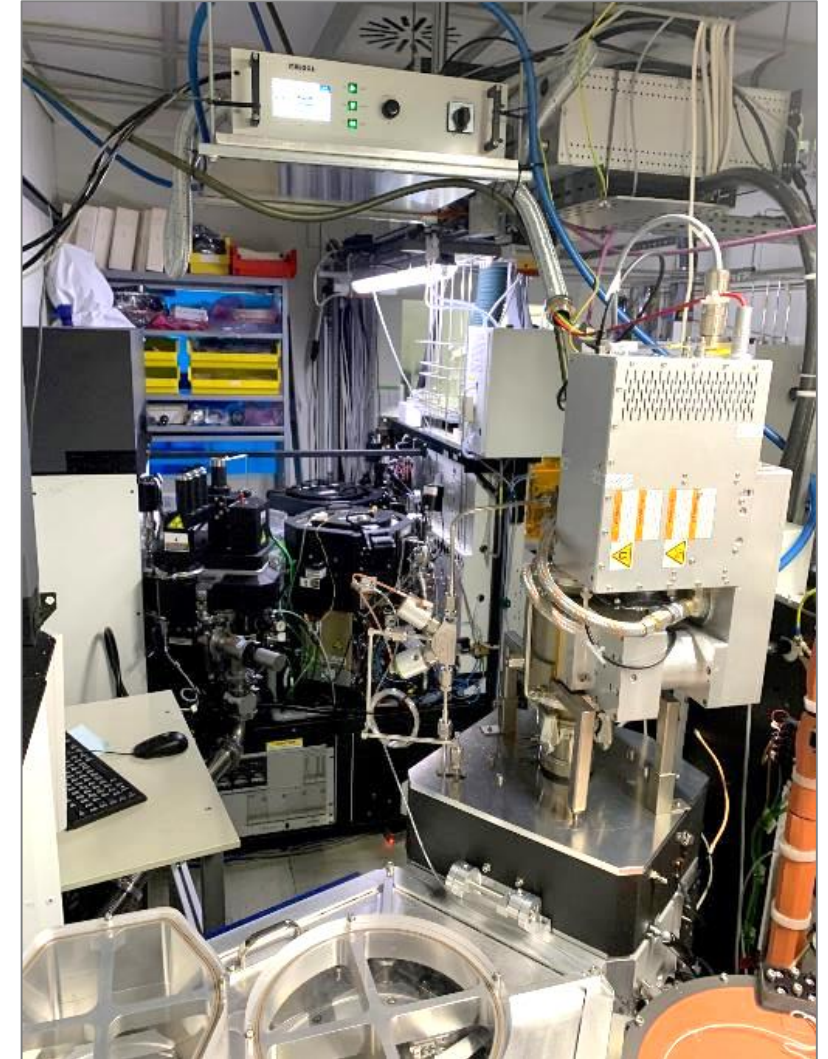
- Very efficient RPS-System
- Sapphire plasma tube; ignites also N_2 or NF_3
- Field test starts Jan 2023



Trace-Rite ep



Industry 4.0 RPS (Muegge)



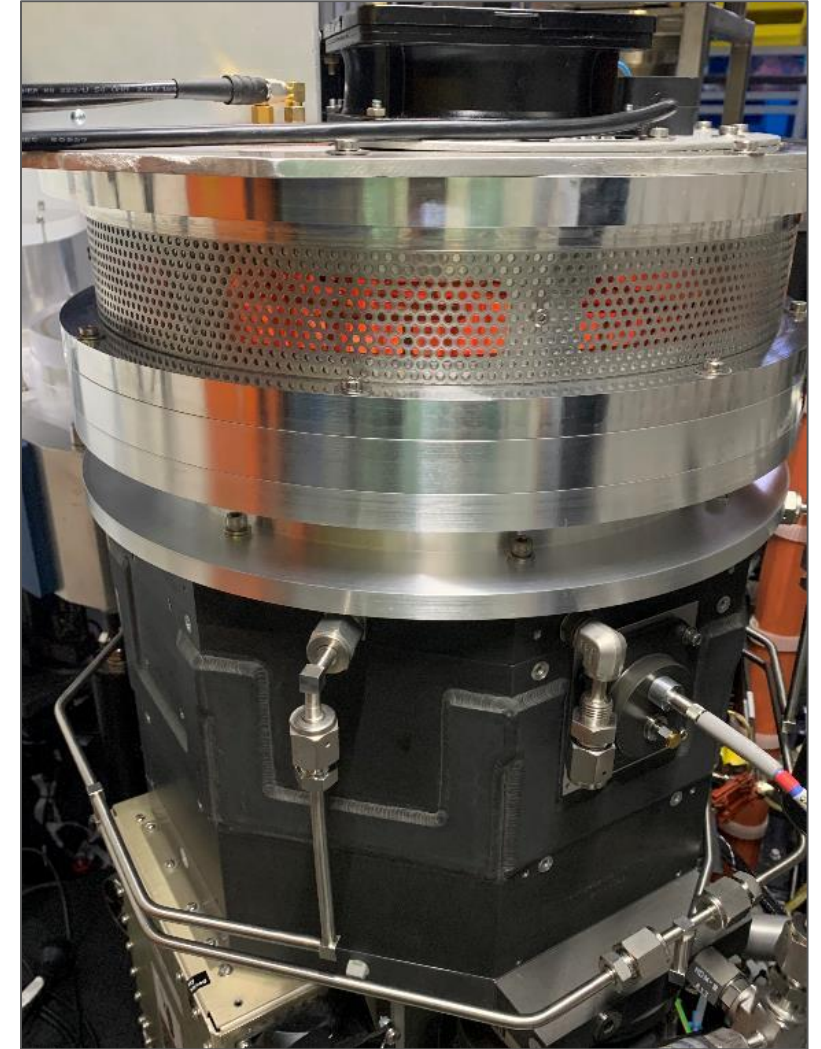
MW-RPS on AMAT DxZ chamber

Green ICT – FAN Gas Etching

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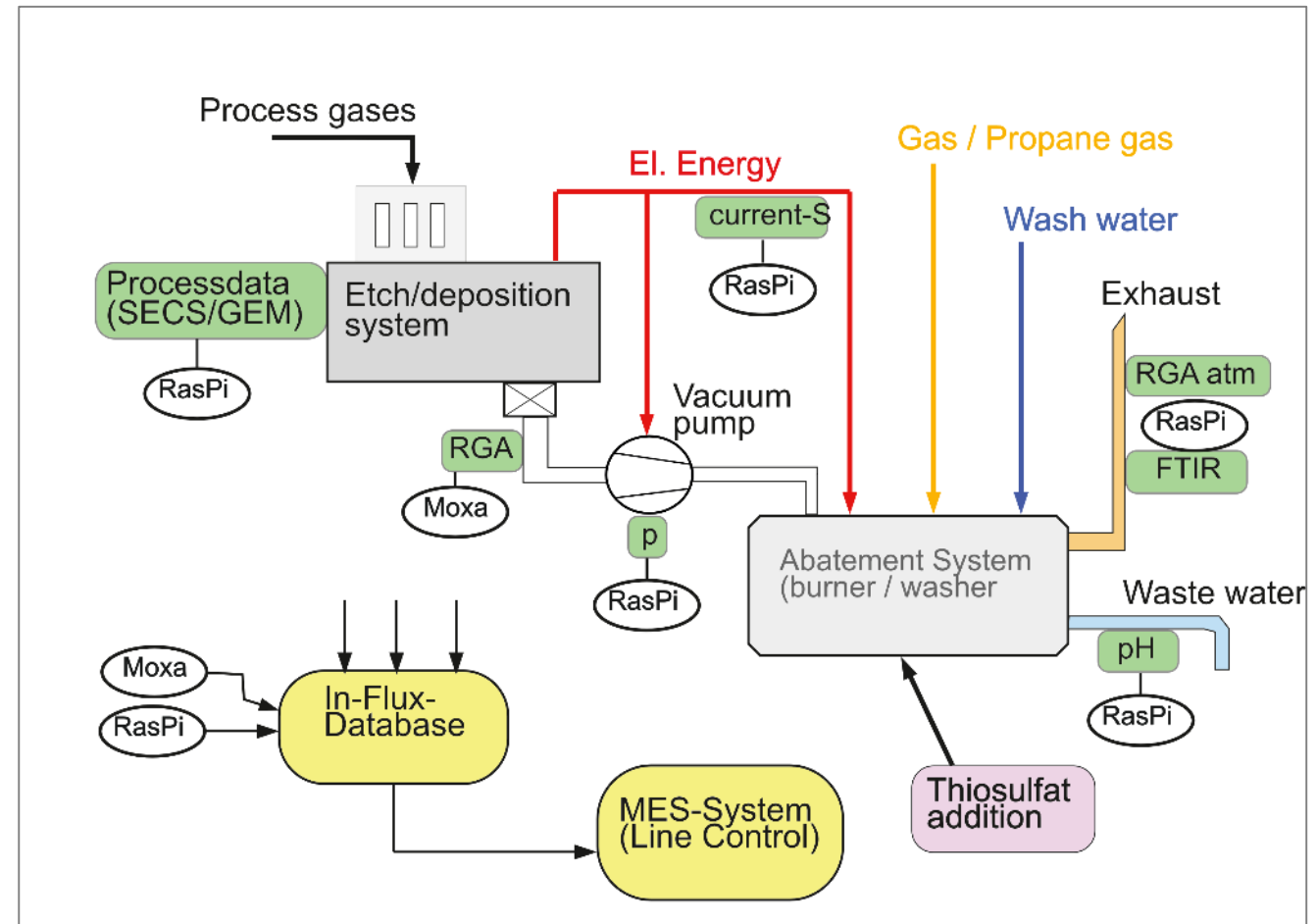
- Used for etch chamber cleaning in Asia/Pacific
- Can replace CF_4 in hard mask etching
- Early Tests to replace SF_6 in DRIE Bosch-process
- New chamber design under test:
INCA (inductive coupled array)



INCA source on modified AMAT P5000 chamber

Green ICT –Abatement Lab at Fraunhofer EMFT

- Fully equipped abatement chain:
 - Influx database –live recording of all related processing data
 - burner/washer
 - FTIR
 - 2 RGA's (before/after vacuum pump)
 - TraceRite ep, optical ep

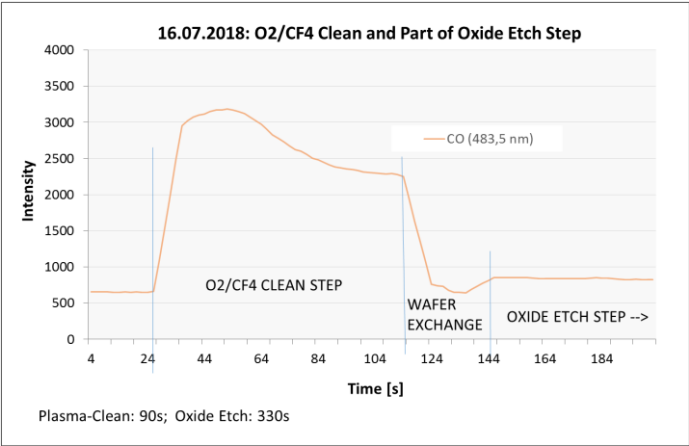


Abatement Lab Schematic

Green ICT –Abatement Lab at Fraunhofer EMFT



Real time thermocouple data



Abatement system with FTIR

Green ICT –Abatement Lab at Fraunhofer EMFT

- **Topics within the Green ICT Hub3, WP 4.3:**
- **Studies to achieve abatement process without burning**
- **Saving waste water**
- **Long-range goal: Re-use of HF and SiF₄ to achieve recycling processes**
- **Data acquisition regarding NO_x**

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Green ICT – Summary and Conclusions

- **FAN gas mixture = etching gas with ~0 GWP**
- **FAN as PECVD-cleaning gas mixture is on its way into early production**
- **SF₆ as an etch gas reaches end-of life; replacement needed**
One possibility: FAN gas mixture, under development
- **New Microwave RPS ready for beta-site**
- **New INCA source under development**
- **Abatement lab: Waste water reduction, clean without burning / just washing**

Thank You for your attention!

Contact

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