



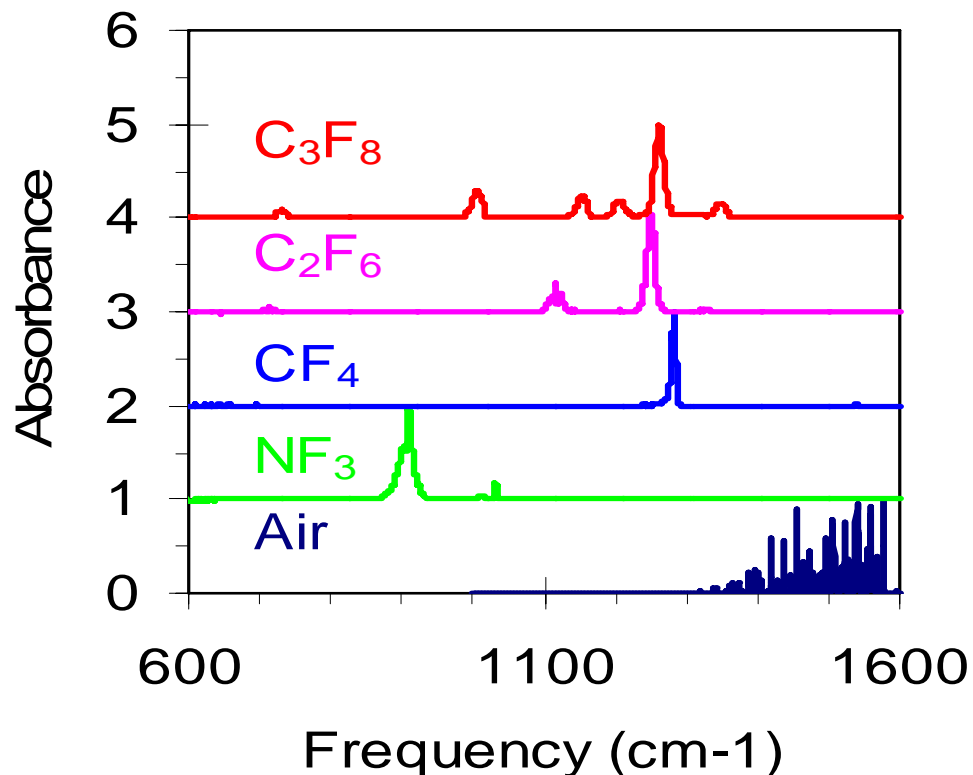
Reducing PFC Emissions Through Advances in CVD and Etch Processing

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Agenda

- **Industry Background on PFC Reduction Initiatives**
- **Measuring semiconductor process emissions**
- **CVD Chamber Cleaning**
 - **Optimizing C₂F₆-based Processes**
 - **Implementing NF₃-based Processes**
- **Plasma Etching**
 - **Alternative chemistries for advanced technologies**

Perfluorocarbon (PFC) Gases

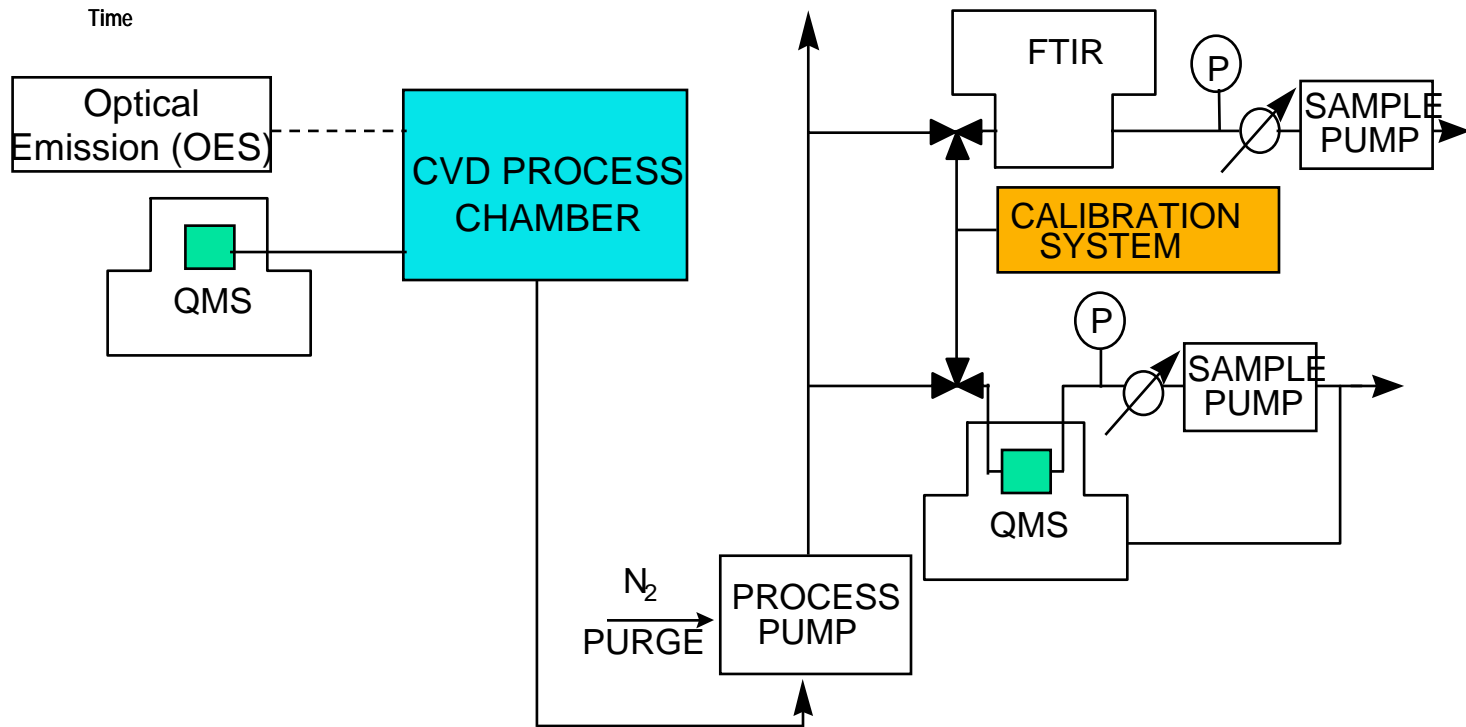
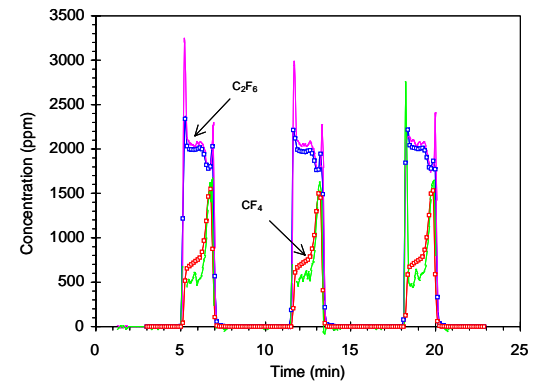
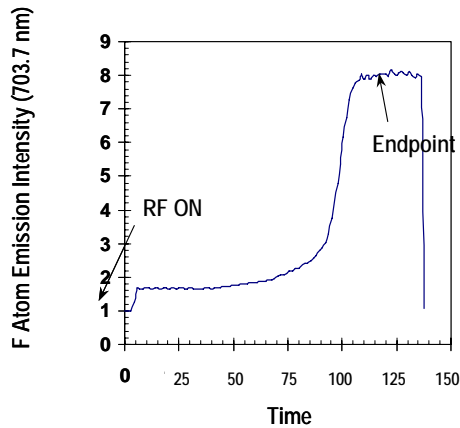


- PFCs suspected of contributing to global climate change due to long lifetimes and strong infrared absorbances
- They absorb light where the atmosphere is otherwise transparent

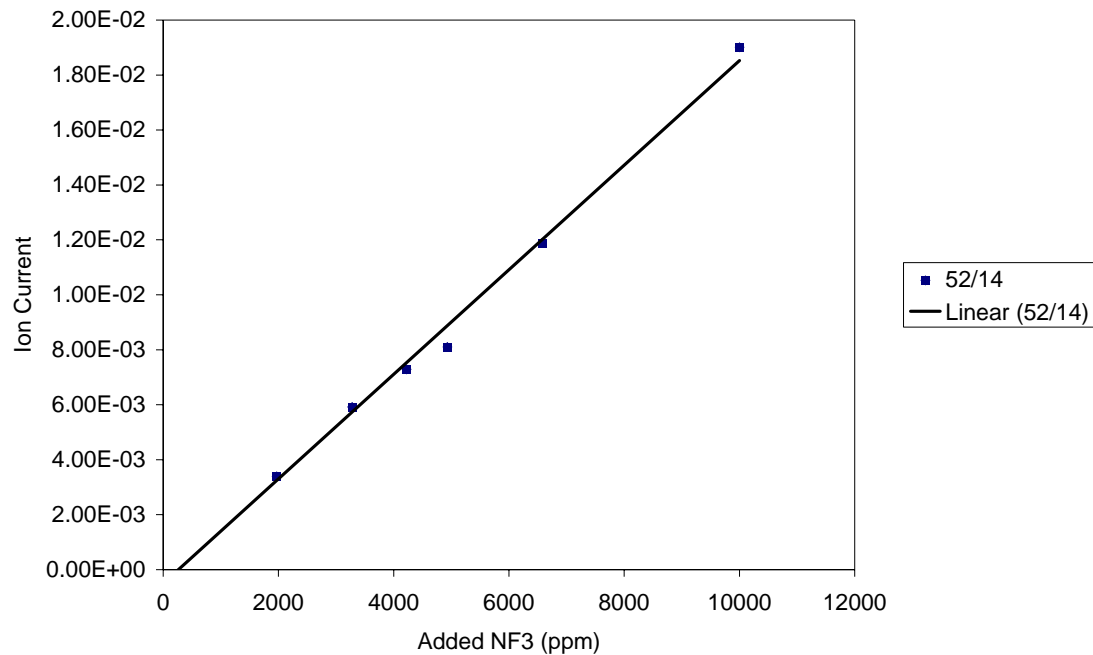
PFC Emissions Reduction

- **PFCs are used in both CVD and Etch processing to manufacture semiconductors**
- **Four Strategies to reduce PFC emissions:**
 - **Process Optimization**
 - **New Compounds**
 - **Recycle/Reclaim**
 - **Abatement**
- **Evaluating the effectiveness of these strategies requires accurate measurement of PFC emissions**

Semiconductor Process Monitoring

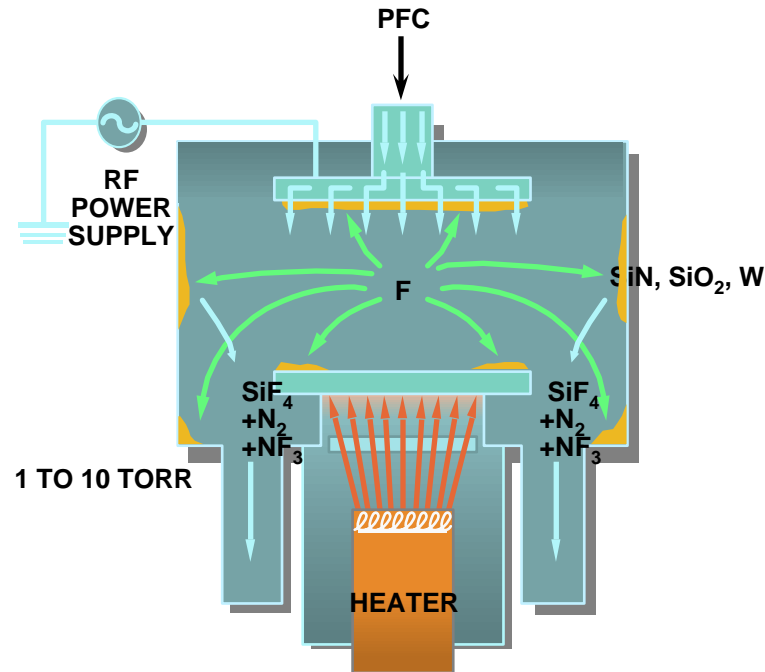


Analytical Capabilities



- **Monitor and calibrate for the following:**
 - **PFCs and FCs: CF_4 , C_2F_6 , C_3F_8 , NF_3 , SF_6 , C_4F_6**
 - **Process byproducts: COF_2 , OF_2 , SiF_4 , HF , F_2 , NO , NO_2**
 - **Acid gases: HF , HCl , Cl_2 , HBr , Br_2 , BrCl , BCl_3 , SiCl_4 , SiF_4 , F_2**
 - **VOCs: methanol, propylene, ethanol, n-methyl pyrrolidinone (NMP), 2-propanol, butyl acetate, acetone, o, m, p-xylene, ethyl lactate, isopropanol amine**

CVD Chamber Cleaning



- Chamber cleans for installed CVD tools inefficiently utilize the PFC gas
- Substantial reductions in PFC emissions and costs are possible by optimizing the chamber clean process

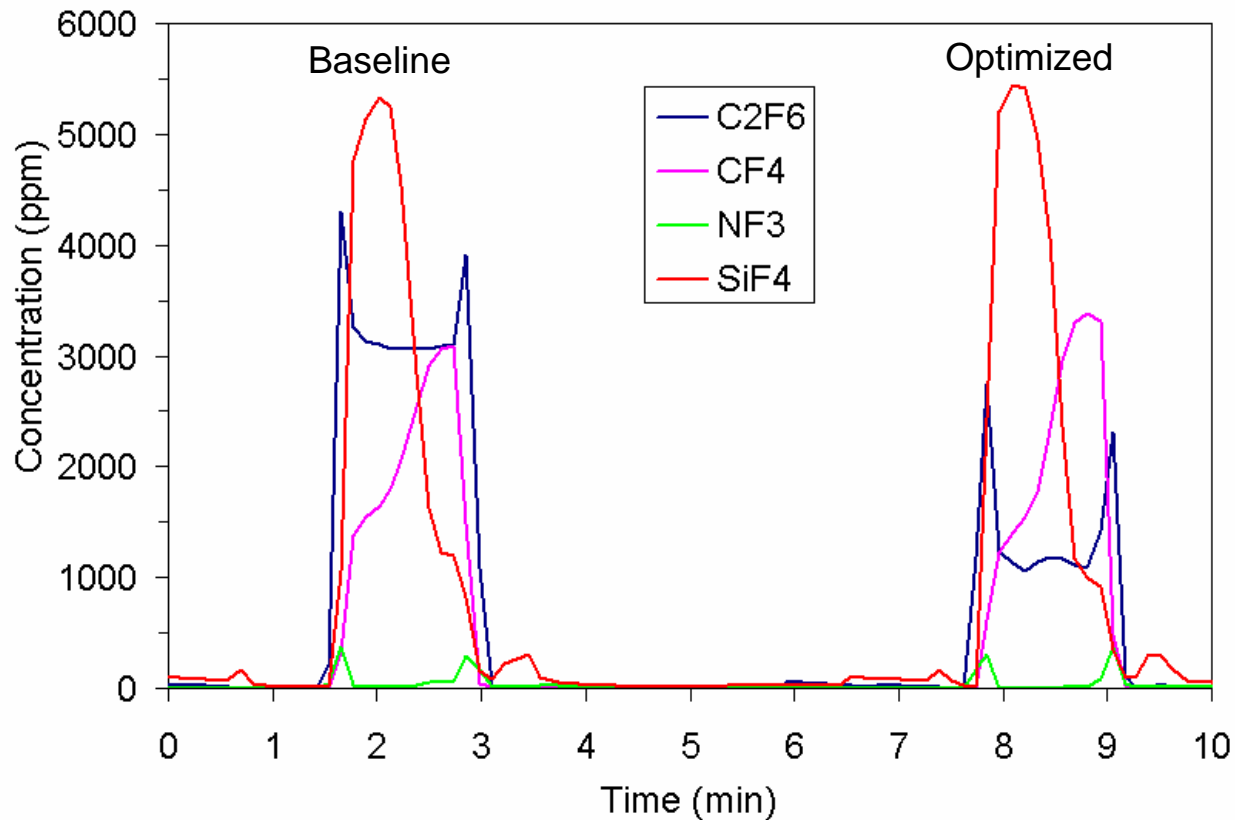
C_2F_6 -Based Chamber Clean Processes

C_2F_6/O_2 Optimization on Actual Productions Tools:

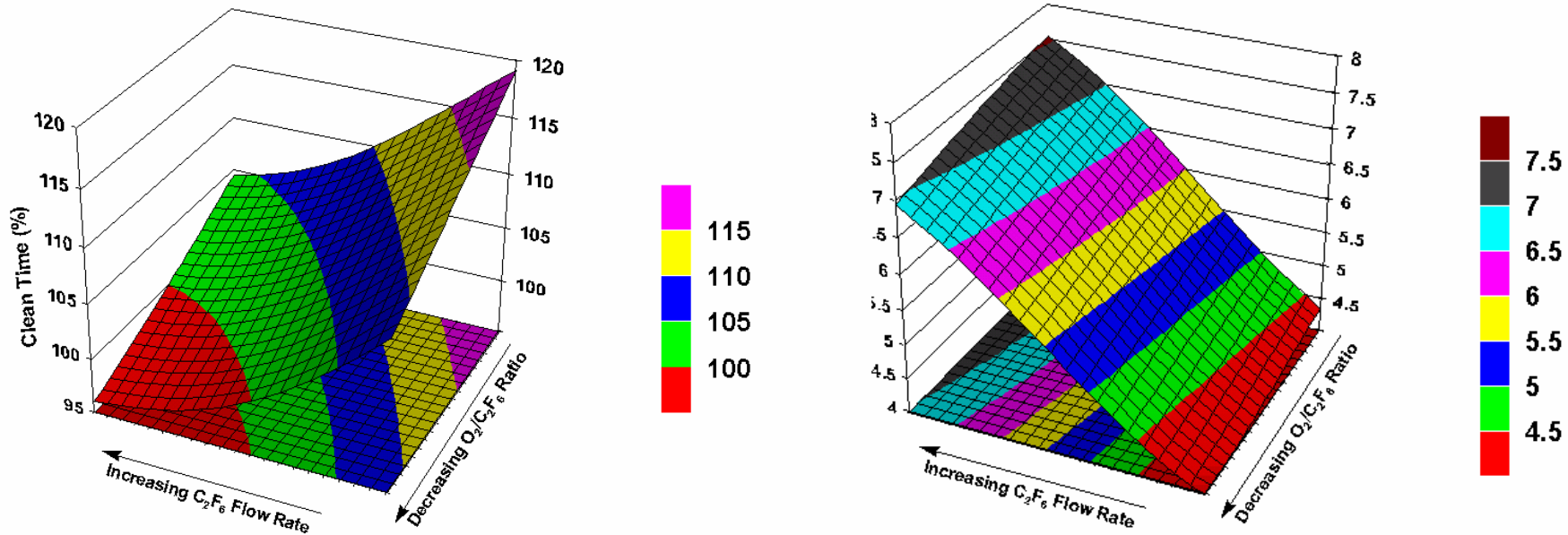
- Applied Materials DxZ (TEOS, TEOS/ O_3)
- Applied Materials DxL (TEOS)
- Novellus Concept One (TEOS, SiN_x , SiON, USG, BPSG)
- Novellus Sequel (SiN_x , USG, PSG, TEOS, BPSG)
- Novellus Altus (W)

Concentration Profile

Applied Materials DxZ (200 mm): TEOS PECVD



Response Surfaces



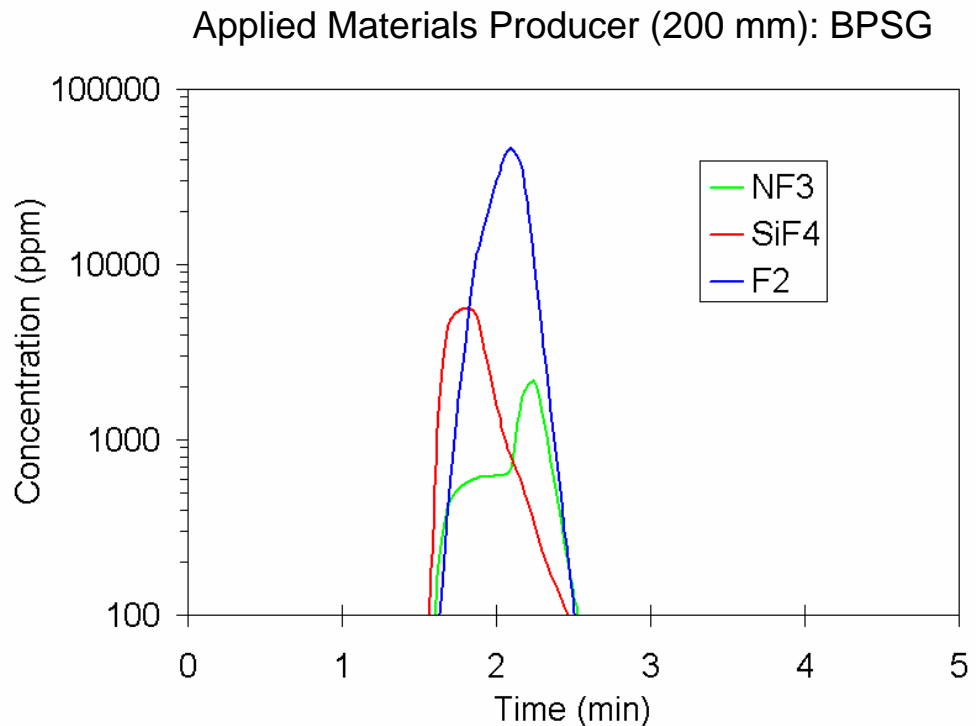
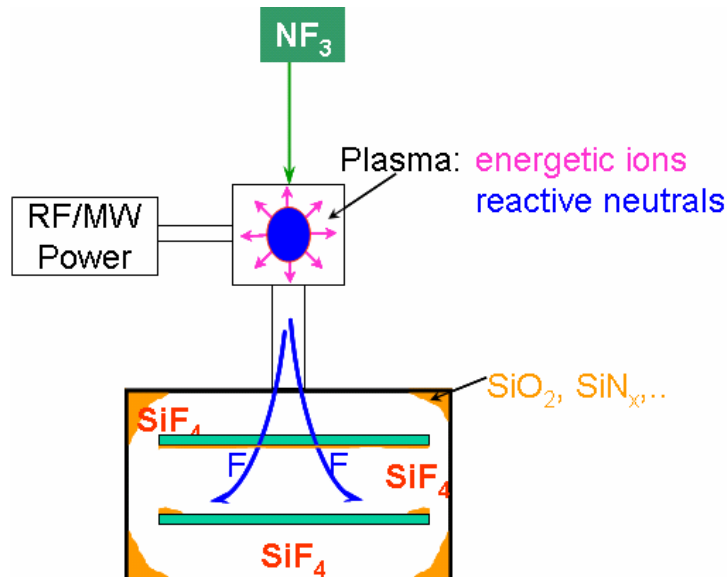
- Response surfaces are used to identify conditions having reduced PFC emissions but the same clean time
- Both faster cleans and lower PFC emissions are obtained by increasing the pressure and decreasing the O₂/C₂F₆ ratio

Optimized Chamber Cleans

	Baseline	Optimized
C ₂ F ₆ (sccm)	400 sccm	260 sccm
O ₂ (sccm)	550 sccm	365 sccm
NF ₃ (sccm)	60 sccm	60 sccm
Pressure (torr)	4.4 torr	5.0 torr
RF Power (W)	2000 W	2000 W
PFC (MMTCE/um)	3.7×10^{-9}	2.1×10^{-9}
SiF ₄ (scc/um)	178	170
Clean time (s)	43	41

- **C₂F₆ concentration during optimized clean (1000 ppm) is lower than baseline (3000 ppm) due to improved utilization**
- **SiF₄ emissions profiles are identical showing optimized clean effectively cleans the chamber**
- **PFC emissions reduced 44 % while maintaining the same clean time (43 s)**

NF₃-Based Chamber Clean



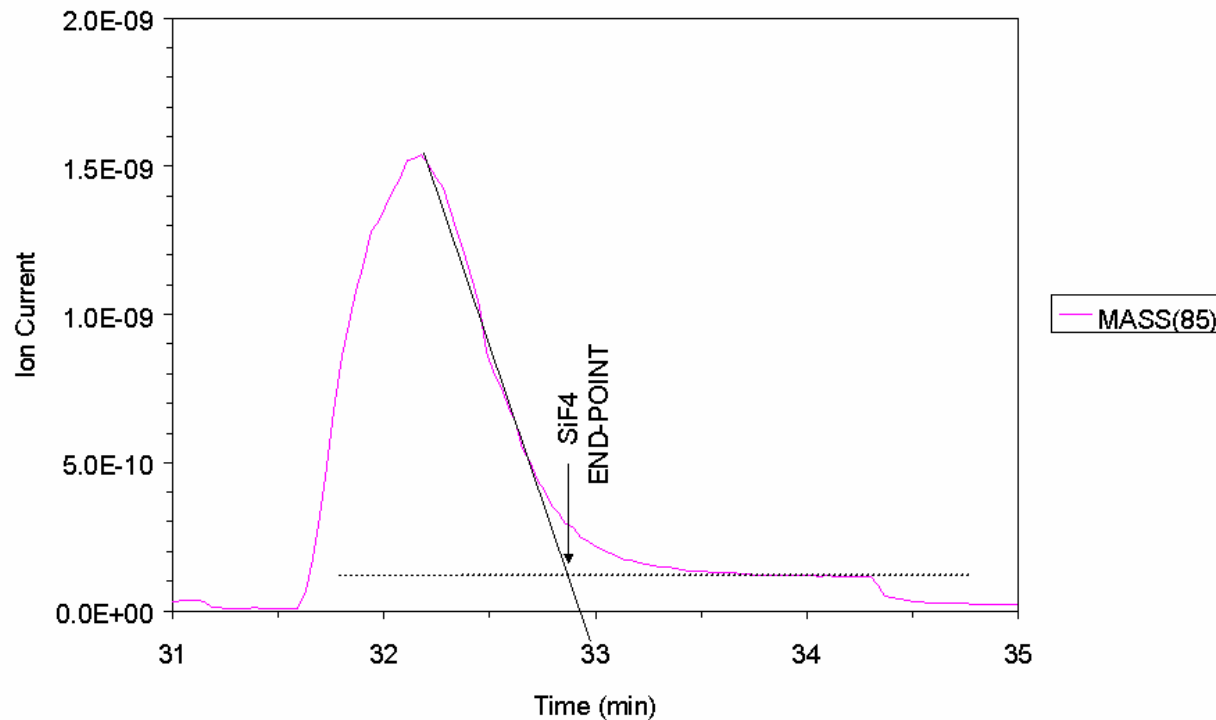
- Provide greater reduction in PFC emissions
- Utilization is better than 95 %

NF₃-based Chamber Cleans

NF₃ Optimization on Actual Productions Tools:

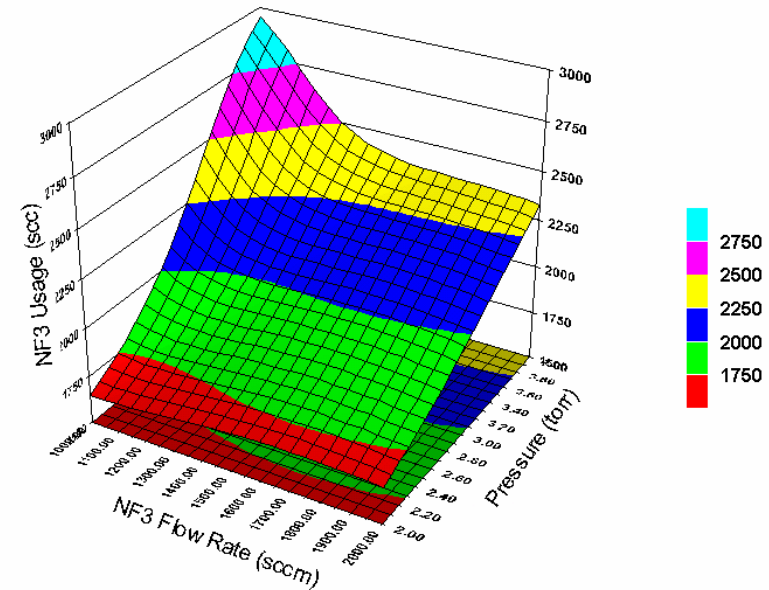
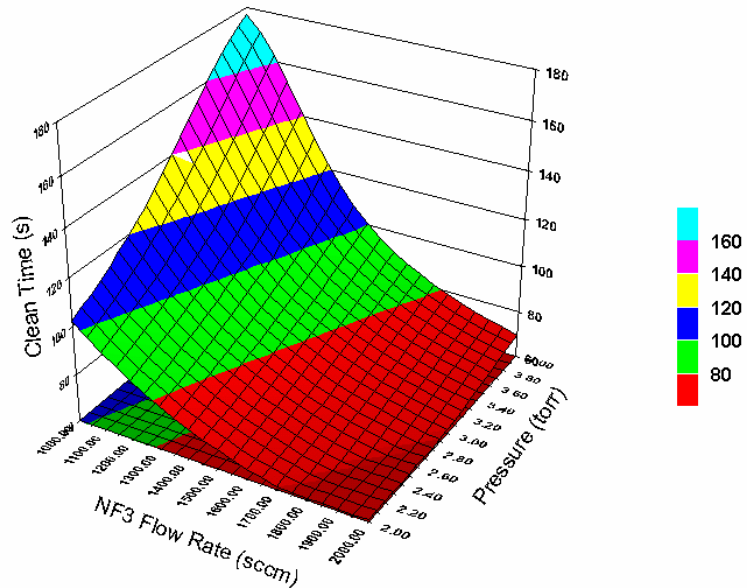
- **Applied Materials Producer (BPSG)**
- **Applied Materials Ultima (USG, FSG)**
- **Applied Materials DxZ (PECVD TEOS)**
- **Applied Materials DxL (SA/PECVD TEOS)**
- **Novellus Altus (W)**
- **Novellus Speed**
- **AMAT Centura (USG)**
- **Mattson Aspen II (USG, TEOS, SiNx, ARC)**
- **Genus 7200 (WSi, WN)**

Measuring Clean Times



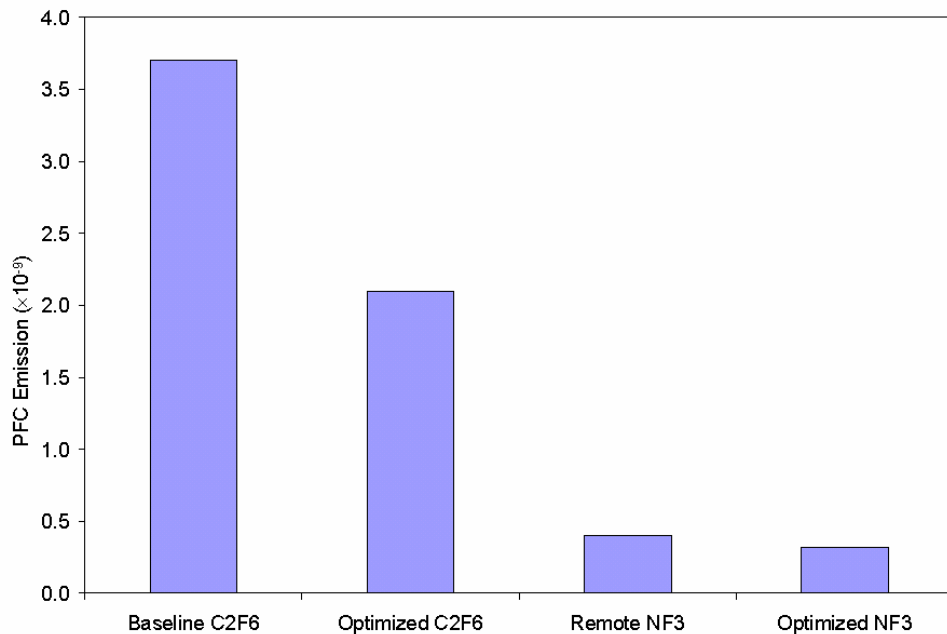
- **Since there is no glow discharge in the CVD chamber during cleaning, OES cannot be used for EPD**
- **In Situ QMS was used as a process monitor**
- **Clean time obtained from the SiF₄ profile**

Response Surfaces



- Response surfaces used to identify conditions having reduced NF_3 usage but the same clean time
- Both faster cleans and lower gas usage are obtained by decreasing the pressure

Summary of PFC Emissions Reduction



- **Optimizing C₂F₆-based cleans substantially reduced PFC emissions and also provide cost reductions (gas usage)**
- **Adopting NF₃-based processes for cleaning CVD chambers provides even further PFC reductions (> 90 %)**
- **Reductions in PFC emissions have been accompanied by improved performance of the chamber clean process: reduced gas usage, faster clean times, and reduced chamber damage.**

Plasma Etching

- **Many etch processes use PFC gases**
- **At each technology node, the type of etch and etch gas have changed (e.g., 250-90 nm)**
- **FEOL Steps**
 - shallow trench, polysilicon gate, nitride spacer and contact etches
- **BEOL Steps**
 - trench, via and barrier etch stop

Trends in FEOL Etching: Polysilicon Gate

CCP	Chemistry	PFC Emission Species	Pounds Carbon Equivalent Emissions
Oxide Breakthrough	CF ₄	CF ₄ /CHF ₃ /C ₂ F ₆	1.6
Nitride Etch	SF ₆	SF ₆	4.7
Nitride Overetch	SF ₆	SF ₆	8.1
Total			14.4
ICP			
Oxide Breakthrough	CF ₄	CF ₄ /CHF ₃ /C ₂ F ₆	1.5
Nitride Etch	CF ₄	CF ₄ /CHF ₃ /C ₂ F ₆	0.6
Nitride Overetch	SF ₆	SF ₆	0.4
Total			2.5

- Number of etch steps has not changed
- Alternative plasma source (CCP and ICP)
- Substantial (5.7x) reduction in PFC emissions by adopting ICP equipment
- Reductions due to lower PFC flow rate and higher PFC utilization
- Other trends reducing PFC emissions:
 - Replace CF₄/CHF₃ with C₄F₈/C₅F₈ (contact etch)
 - Replace SF₆ with Cl₂ (spacer etch)

Trends in BEOL Etching: Metalization

Node (nm)	Etch	Chemistry	Byproducts	Emissions [#]
250	Via	CF ₄ /CHF ₃	CF ₄ /CHF ₃ /C ₂ F ₆	5.8
130	Via & Trench	C ₄ F ₈	C ₄ F ₈ /CF ₄ /CHF ₃	0.68
90	Via & Trench	C ₄ F ₈ /C ₄ F ₆	C ₄ F ₈ /CF ₄ /CHF ₃	0.44

- Major trends have been adoption of damascene metallization scheme and changes to dielectric material (e.g., FSG, CDO)
- Etch requirements (e.g., aspect ratio and selectivity) have required use of alternative etch gases (e.g., C₄F₆)
- The number of etch steps has increased, however, the newer etch gases required have lower PFC emissions
- Advanced technology nodes have a significant decrease in PFC emissions (54 %)
- If the number of metal layers increases from 6 to 8, cumulative PFC emissions are still reduced 15 %

Summary

- **The semiconductor industry has focused on protecting the environment while also creating strong economic growth by improving device performance and reducing costs**
- **Advances in CVD and etch processing have resulted in reductions of PFC emissions while also improving performance**
- **PFC reductions of 43% were obtained by optimizing the existing Applied Materials DxZ chamber clean. Gas costs are also reduced 35 %. Similar reductions are possible for other films and equipment**
- **Even greater PFC reductions are possible by implementing NF_3 based chamber cleans (90% for an Applied Materials Producer chamber)**
- **The use of high density plasmas and newer etch gases (e.g., C_4F_6) have reduced PFC emissions despite an increase in the number of plasma etch process steps**



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