PFC Emission Reduction in Installed-Base CVD Tools: Some Recent Fab Results

Gary Loh

DuPont Electronic Gases

CEBSM Weekly Seminar, 11/20/2003

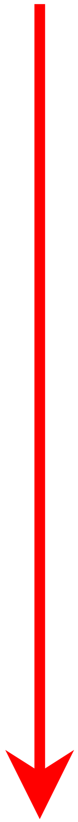
The miracles of science™

Trends in CVD chamber cleaning

- Newer-generation tools typically specify NF_3-based cleans
  - low PFC emissions
  - other process considerations
- However, this option may not be viable for existing installed-base tools
  - conversion costs & resources
  - broader fab considerations

Cleaning process options for installed-base tools

- Continue to use present standard process (commonly C_2F_6 based)
- Further optimize present process chemistry
- Convert to a “drop-in” replacement (other C_xF_y)



Amount of time, costs, and other resources to implement

Option choice involves several factors

- Economic
  - Gas usage/costs
  - other (e.g., abatement, tool kit changeout)
- Process performance
  - Clean time (throughput)
  - Clean efficiency (completeness of clean)
- ESH
  - PFC emissions
  - other emissions (e.g., HAPs)
  - health & safety factors

An example of C_2F_6 process optimization

- Presented by Philips Semiconductor and Air Products at this year's (10th) ISESH Conference; summary of Novellus C-2 DOE results:

	Base-line process (HP/LP)	**BPTEOS (HP/LP)**		**USG (HP/LP)**		**SiN_x (HP/LP)**	**SiN_x+BPTEOS (HP/LP)**	
	MOS3	**BPT-1**	**BPT-2**	**USG-5**	**USG-1**	**SiN-3**	**MIX-1**	**MIX-2**
C_2F_6 (sccm)	2500/2500	1750/1250	1250/1250	1750/1250	1250/1250	1750/1250	1750/1250	1250/1250
O_2 (sccm)	2000/2000	1400/1000	1000/1000	1400/1000	1000/1000	1400/1000	1400/1000	1000/1000
P (torr)	2.70.7	3.2/0.7	2.7/0.7	3.2/0.7	3.2 /0.7	3.0/0.7	3.2/0.7	2.7/0.7
RF power (W)	3500/2500	3500/2500	3500/2500	3500/2500	3500/2500	3500/2500	3500/2500	3500/2500
Clean time (s)	-	773 (+5 %)	795 (+8 %)	838 (+1 %)	884 (+6 %)	928 (+2 %)	903 (+2 %)	968 (+10 %)
PFC emission (MMTCE)	-	$2.27x10^{-7}$ (-29 %)	$1.87x10^{-7}$ (-53 %)	$2.52x10^{-7}$ (-43 %)	$2.12x10^{-7}$ (-52 %)	$2.78x10^{-7}$ (-42 %)	$2.69x10^{-7}$ (-43 %)	$2.20x10^{-7}$ (-53 %)
C_2F_6 Usage (g)	-	119 (-34 %)	102 (-43 %)	130 (-39 %)	113 (-47 %)	146 (-37 %)	142 (-37%)	124 (-45%)

- Acceptable results from additional tool and film evaluations

Drop-in replacement trends for C_xF_y gases

C1 ⇒ C2 ⇒ C3 ⇒ C4

CF_4 C_2F_6 C_3F_8 C_4F_8

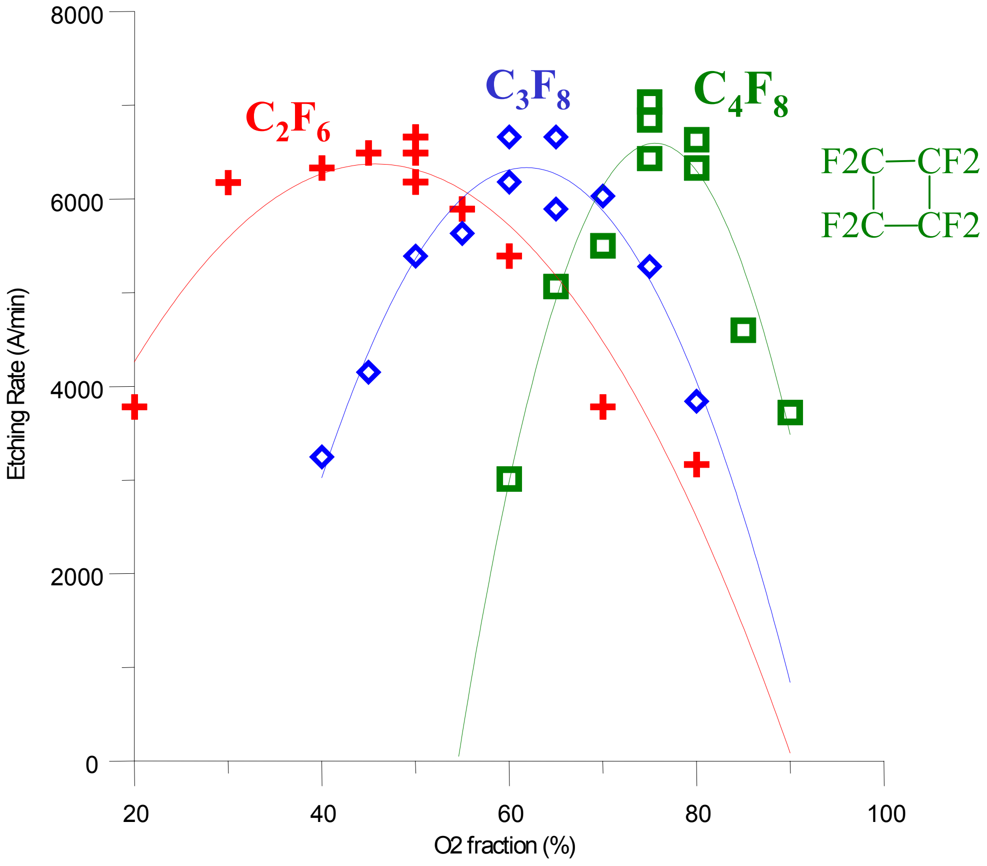
C_4F_8O

decreasing PFC emissions

decreasing gas usage

- Trends based on the decreasing stability of the compounds with increasing x, and so their more efficient conversion to atomic fluorine, the active cleaning species
- Why stop at C4?
  - Availability and fab experience
  - Use considerations, especially vapor pressure

Initial proof of concept for C_xF_y trend



- CVD test reactor at MIT: capacitively coupled, symmetrical parallel-plate configuration
- Etch rate of PETEOS oxide at 385°C versus O_2 content, fixed other parameters

First confirmations in installed-base process tools

(C_4F_8 vs C_2F_6)

- **Novellus Concept-1 (200mm) -** DOE (% O_2, total flow, pressure)

  > 80 % reduction PFC emissions (kg CE)

  > 60 % Reduction in gas consumption (wt)

  (Ref: CVD Chamber Cleaning: A Critical Comparison…, *Semicon West 2000)*

- **AMAT P-5000 (DxL) -** DOE (% O_2, total flow, pressure)

  > 60-90 % reduction in PFC emissions

  > 60 % reduction in gas consumption (wt)

  (Ref: *ISMT Tech Transfer Report #01024083A-TR*

Fab example #1: C_3F_8 replacement by C_4F_8 at AMD

Fab 14/15 - Novellus Concept 1 (150 mm)

Fab 25 - Novellus Concept 2 (200mm)

- AMD Goals: Reduce Gas Costs

  Reduce PFC Emissions > 50%

  Maintain or improve clean time

  Maintain or improve film/tool performance

  Multiple films (Silane, TEOS, Oxynitride, BSG, BPSG)

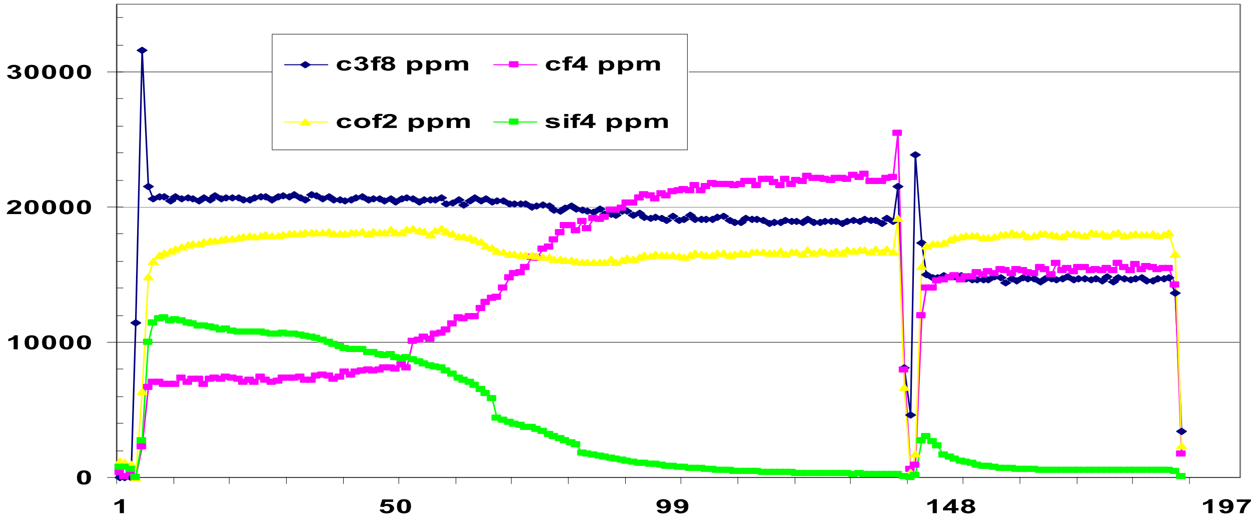
AMD has published two papers on these studies:

- A. Evans, ***International Semiconductor ESH Conference***, San Diego CA, June 2002.
- ***Semicon Southwest***, Austin October 2002.

Clean process parameters monitoring by FTIR

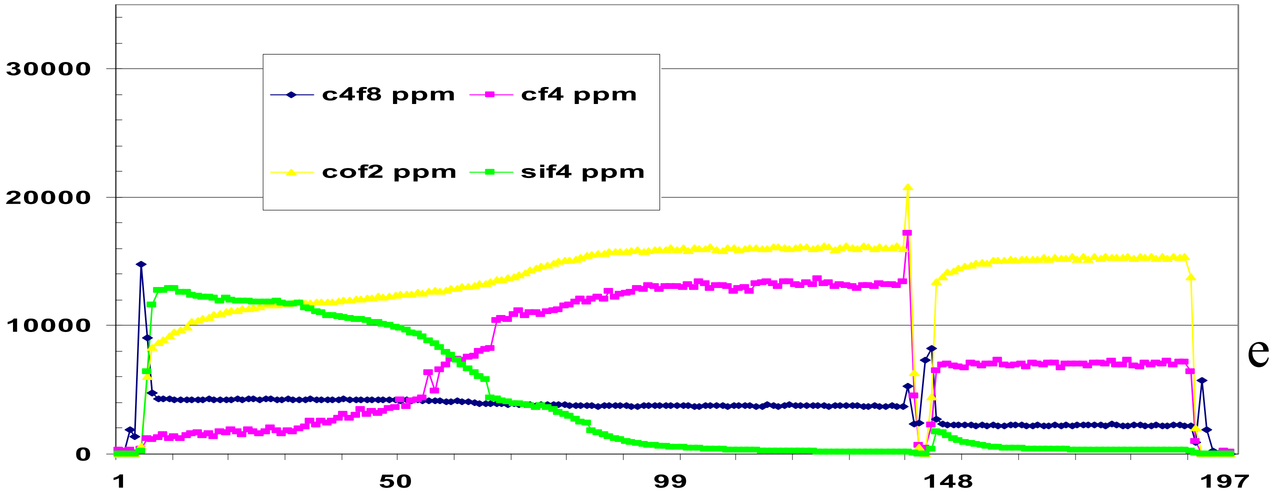
C3F8 Chamber Clean

(59 % O2, 1270 sccm C3F8, 3.2 torr, 2500W)



C4F8 Chamber Clean

(77% O2, 500 sccm C4F8, 3.0 torr, 2500W)



Novellus C2-Sequel

- 25 wafer lots
- silane oxide film

<u>Gas usage reduced</u>:

> 60 wt %

<u>PFC emissions reduced</u>:

> 75 %

(all with no loss of clean efficiency, measured by total SiF_4 produced)

Process comparison summary

(50 Wafers of 11,500A Silane Oxide)

	C4F8	C3F8
HP EP Clean Time	13:32	13:37
LP Clean Time	3:02	7:16
Total Time	16:34	20:53
Cost per Wafer	$0.073	$0.276
Emissions	0.13	1

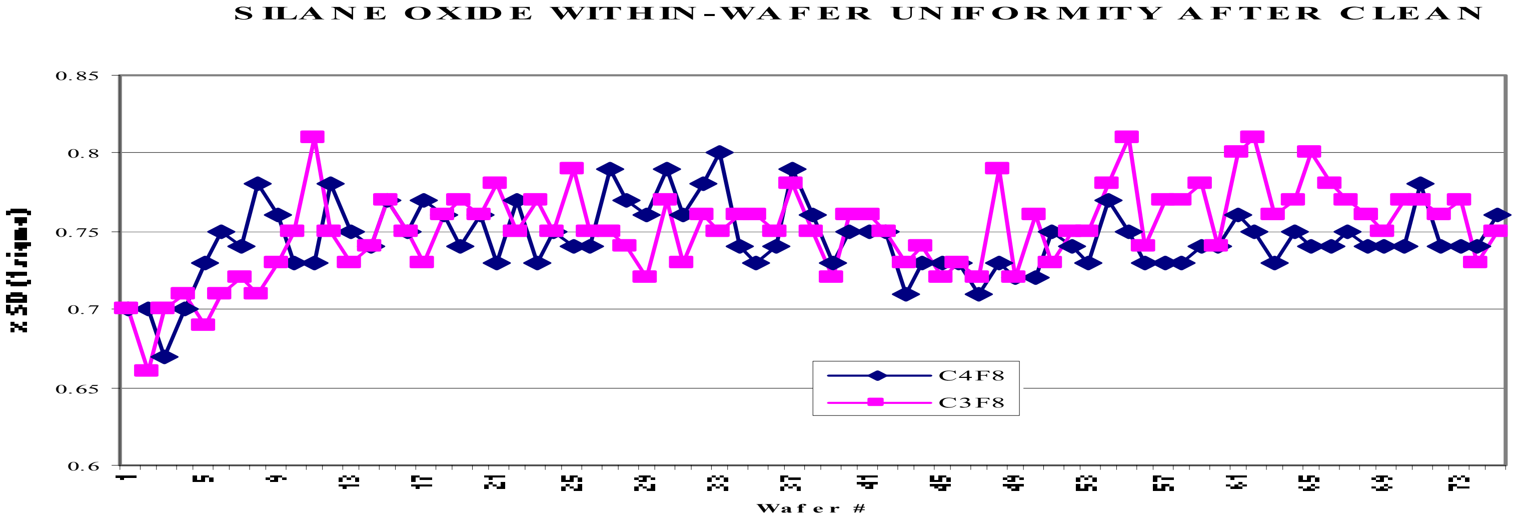
Factor type:

Process performance

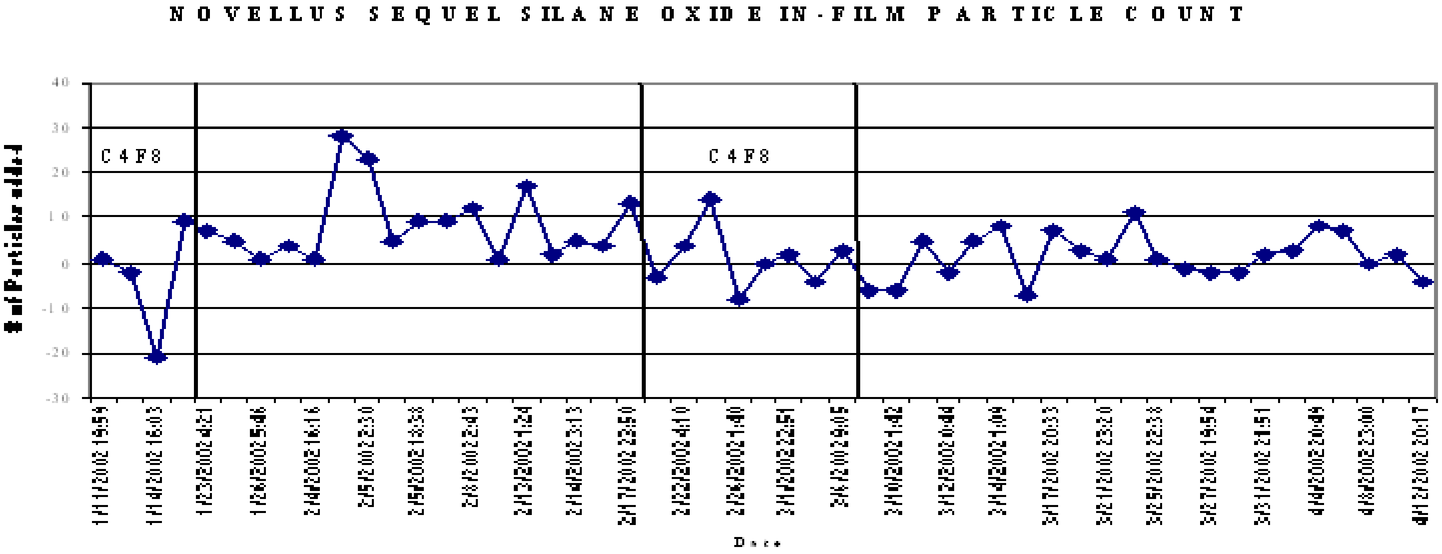
Economic

ESH

CVD film data - a requirement for fab implementation

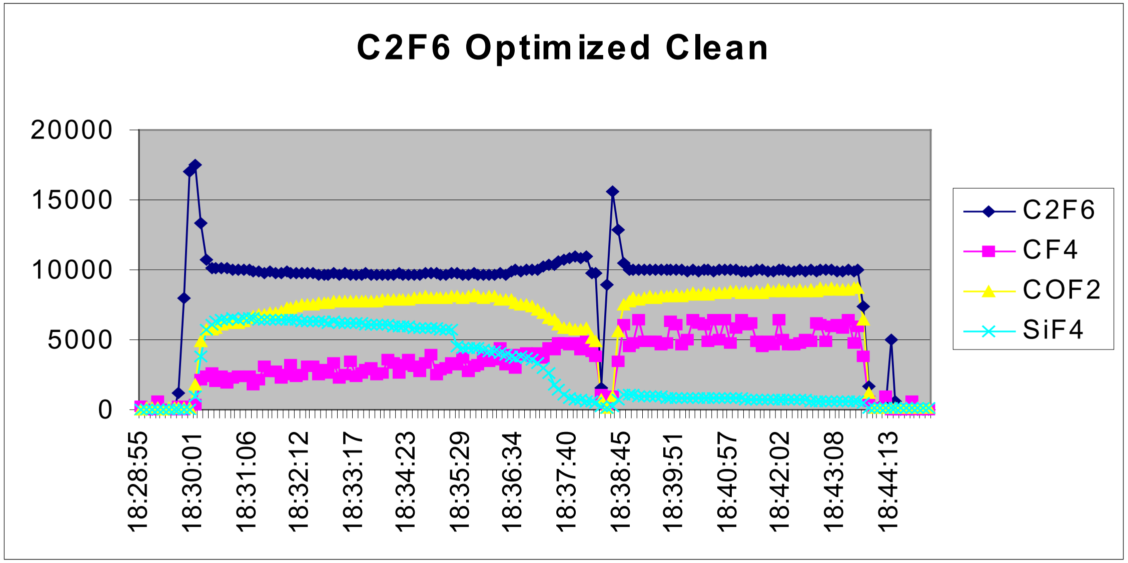


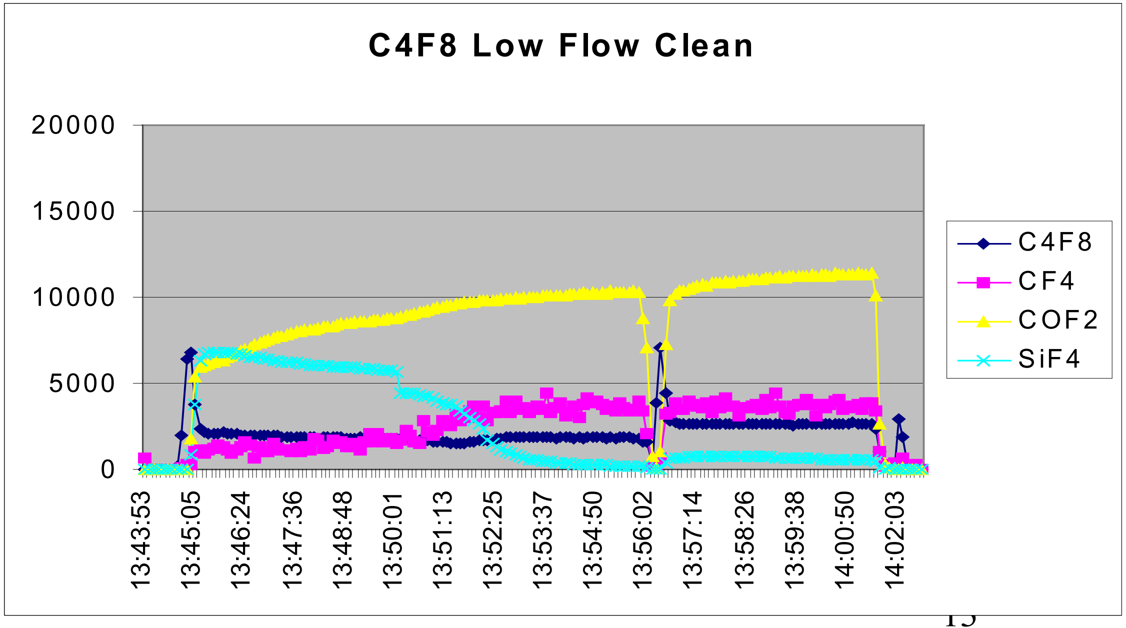
No changes in key film properties (uniformity, particle adders)



Fab example #2: C_4F_8 Conversion at NEC

(FTIR Data on Novellus Concept-1)


C2F6 Optimized Clean


C4F8 Low Flow Clean

Goal:

Reduce cost and PFC emissions with at least equivalent clean time

Test Results (vs C_2F_6)

- Gas usage reduced: 43 wt %
- PFC emissions reduced: 64 %
- Clean time reduced: 4%

Status

Converted to C_4F_8 on Novellus C-1 and C-2

CEBSM Weekly Seminar, 11/20/2003

The miracles of science™

CVD film data at NEC

(Production Test Data on Novellus Concept-1)

Figure 5. Patterned Wafer Defect Map Summary

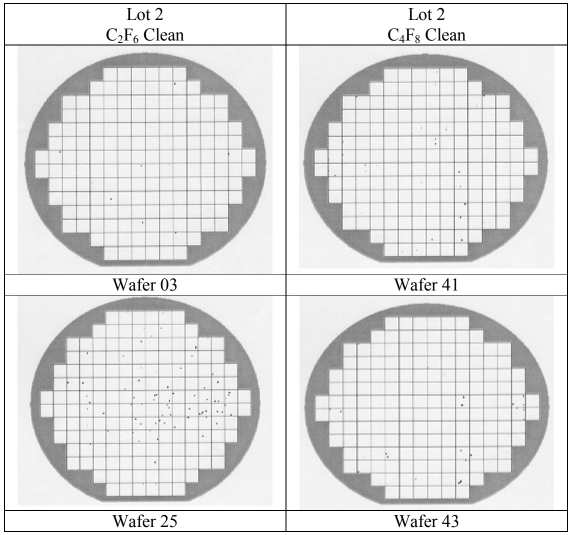


Table 2. Normalized Split Lot Results

LOT NUMBER	PRODUCT TYPE	NORMALIZED YIELD	
		C_2F_6 CLEAN	C_4F_8 CLEAN
1	A	0.97	1.00
2	A	0.97	0.93
3	B	1.06	1.10

Table 3. Patterned Wafer Defect Summary

Lot #	Clean	Wfr #	Total Defects	Under Particle	Color Variation	Particle	All Pattern Defect	False	Unclassified
2	C_2F_6	03	11	6	0	0	5	0	0
		25	74	49	8	14	2	1	0
	C_4F_8	41	42	12	8	8	3	11	0
		43	70	40	23	0	0	0	7

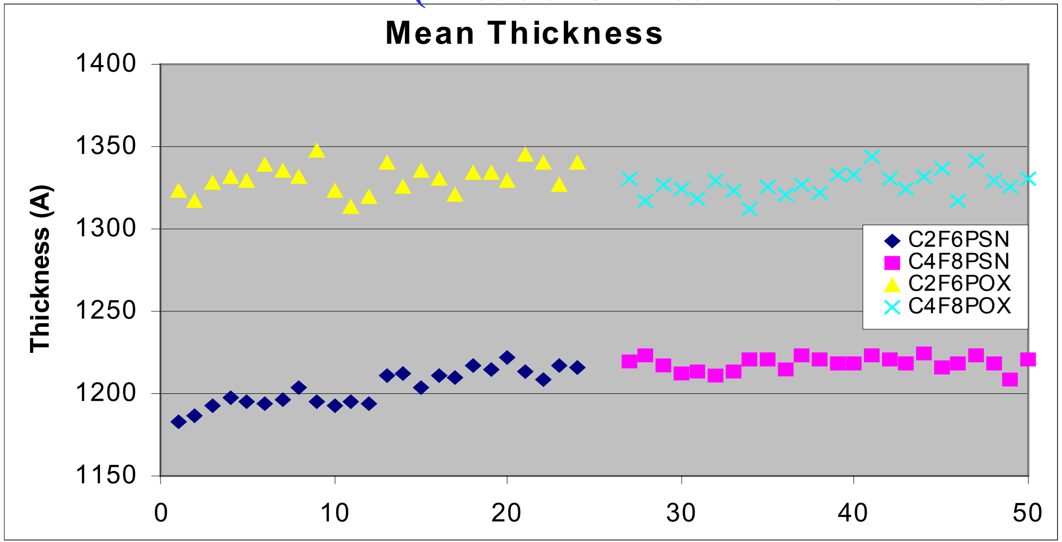
Conclusions:

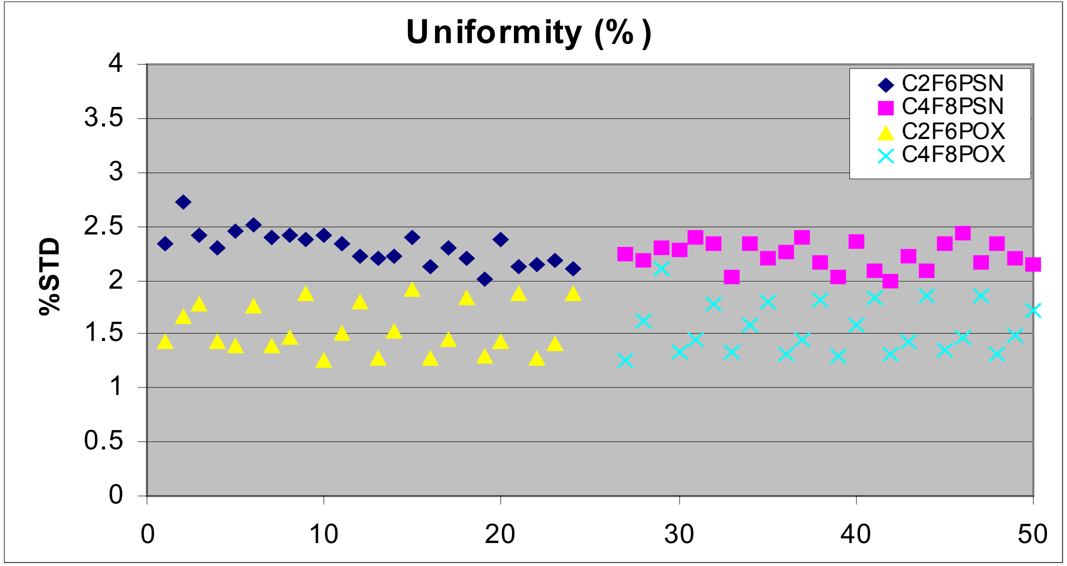
C_4F_8 clean is comparable to C_2F_6 clean for all tested properties:

- particles
- defects
- yield

Fab example #3. C_4F_8 Conversion at TriQuint Semiconductor

(Production Test Data on Mattson Aspen II PECVD)





Goal:

Reduce cost and PFC emission with at least equivalent clean time

Test Results (vs C_2F_6)

- Gas usage reduced: 65 wt %
- PFC emissions reduced: 78 %
- Clean time reduced: 6%
- Comparable film quality and yield

Status

Converted to C_4F_8

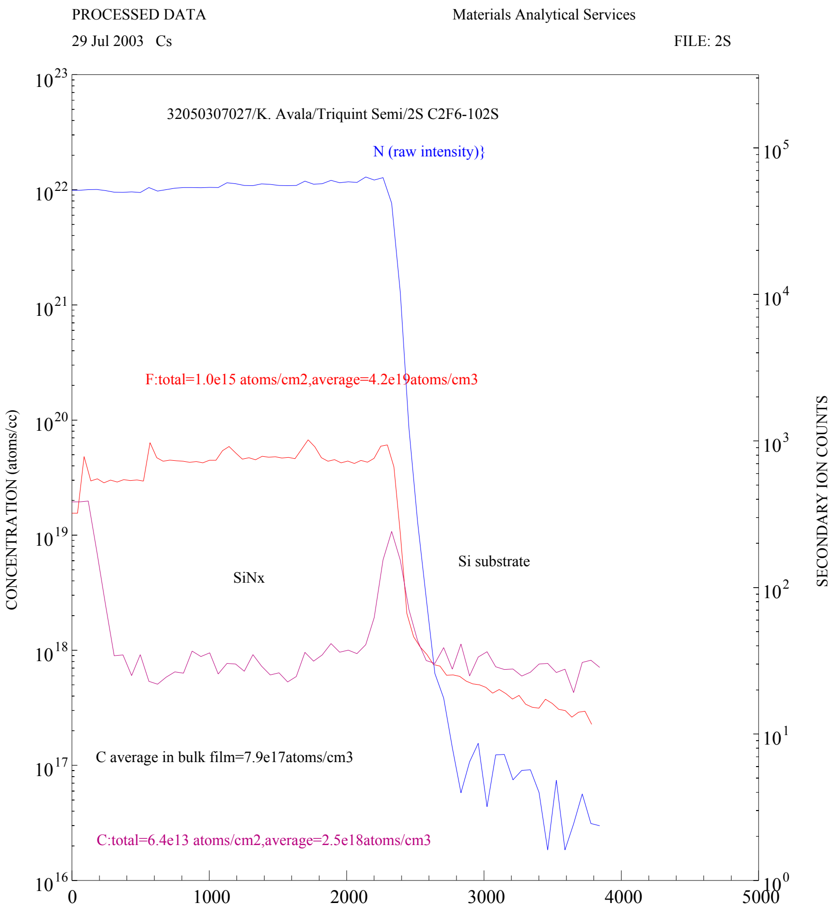
DUPONT

The miracles of science™

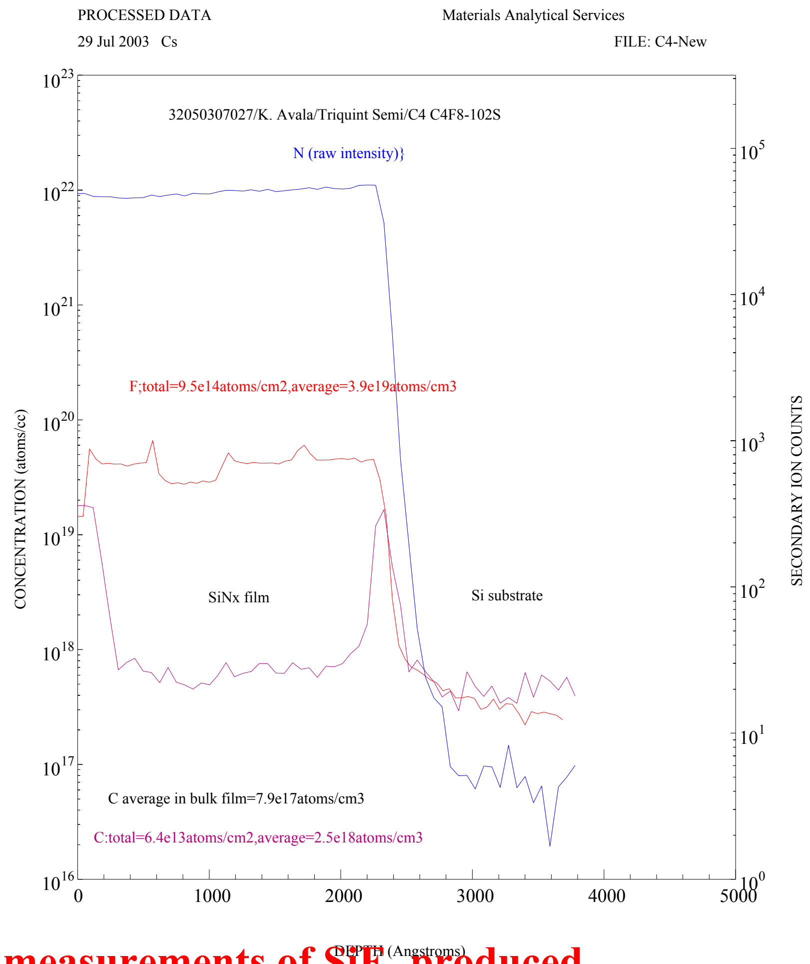
Film-based assessment of cleaning efficiency

(SIMS depth profiles of C and F on SiN film deposited)

After C_2F_6 Clean



After C_4F_8 Clean



Confirmation of efficiency data from FTIR measurements of SiF_4 produced

Summary

- Installed-base CVD tools' clean step performance can often be improved by process optimization or C_xF_y drop-in replacement.
- Basic data through fab results indicate that C_4F_8 is the best of the C_xF_y gases.
  - Lowest gas consumption and PFC emissions, at least equivalent process performance, no adverse effects on film properties and yield.
  - Benefits confirmed for many film types and tool configurations.
- Further details available at www.dupont.com/zyron

Acknowledgements

- DuPont Electronic Gases
  - C. Allgood, S. Hsu, S. Moiyadi, M. Mocella
- MIT
  - H. Sawin, H. Chae, O. Kwon
- ISMT
  - B. Birmingham, J. Soucy
- AMD
  - A. Evans, L. Nevala, M. Sledz, J. Harmon, R. Kasson
- NEC, Electronics America
  - E. Chan, M. Darrah
- Triquint Semiconductor
  - K. Avala, L. Liu, D. Brindza
- Novellus Systems
  - J. Langan, M. Boxx