SCALING OF PFC ABATEMENT USING PLASMA BURN BOXES*

Xudong “Peter” Xu and Mark J. Kushner
University of Illinois
Department of Electrical and Computer Engineering
Urbana, IL 61801

November 1998

***Work supported by National Science Foundation and Semiconductor Research Corp.**

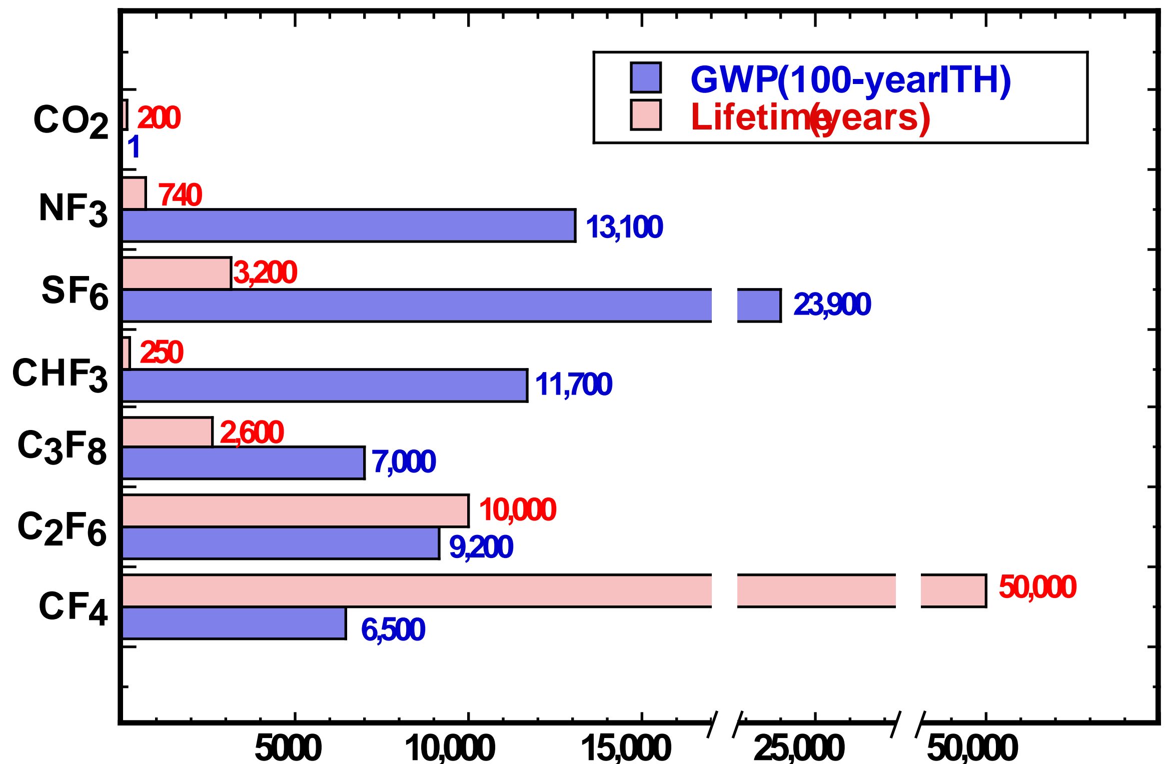
AGENDA

- Introduction
- Geometries of Etching Reactor and Burn Box
- Plasma Chemistry for Ar/PFCs/O_2
- Consumption and Generation of PFCs in Etching Reactor
- Comparison of Predicted C_2F_6 Abatement with Experiments
- Plasma Remediation of PFCs in Burn Box
- Concluding Remarks

PERFLUOROCOMPOUNDs (PFCs)

- **Perfluorocompounds (PFCs) are widely used as process gases in microelectronics fabrication for etching and chamber cleaning.**

- **PFCs are absorbers of infrared radiation having long atmospheric lifetimes and thus have high global warming potential.**



* J. V. Gompel and T. Walling, Semiconductor International, Semp., 1997, p95

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INVESTIGATION OF PLASMA GENERATION AND REMEDIATION OF PFCS

- Since finding suitable substitutes for PFCs is unlikely, remediation of the effluent of plasma etching reactors must be done.

- Destruction of C_2F_6 by plasmas has been experimentally demonstrated in low pressure devices.

- Computer modeling is a useful tool for investigate the physical processes occurring in plasma remediation of PFCs.

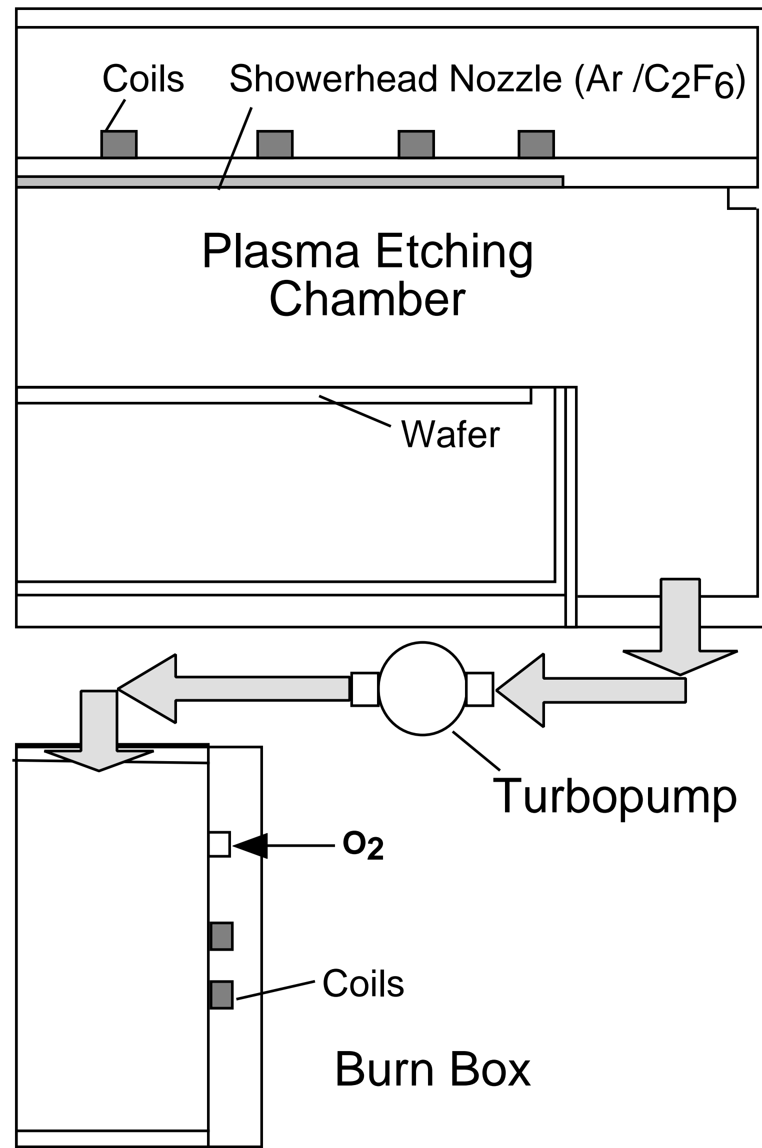
- 2-d HPEM simulations have been performed to investigate
  - Consumption and generation of PFCs in ICP etching reactors
  - Abatement of PFCs in a plasma burn box

GEOMETRIES OF ETCHING REACTOR AND PLASMA BURN BOX

- The test system consists of a plasma etching chamber and a downstream plasma burn box.

- The plasma etching chamber is a 13.56 MHz ICP reactor using Ar/C_2F_6 at 10 mTorr. A 20 cm diameter wafer sits on the substrate

- The burn box, which is down stream of the turbopump, is also an ICP reactor with O_2 injection at the higher pressure of 150 mTorr.



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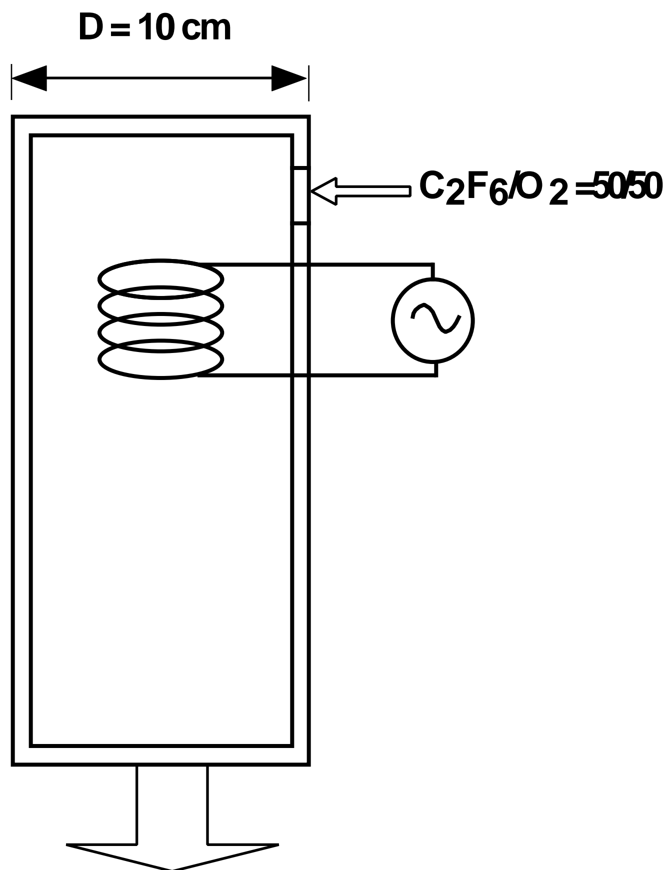
OXIDATION CHEMISTRY IN BURN BOX

EXPERIMENTAL ABATEMENT OF C_2F_6 IN BURN BOX

- Sawin and Vitale * investigated the abatement of C_2F_6 in an ICP burn box using an internal coil.

- C_2F_6: 200 sccm
- O_2: 200 sccm
- Pressure: 500 mTorr



* 51st Annual Gaseous Electronics Conference

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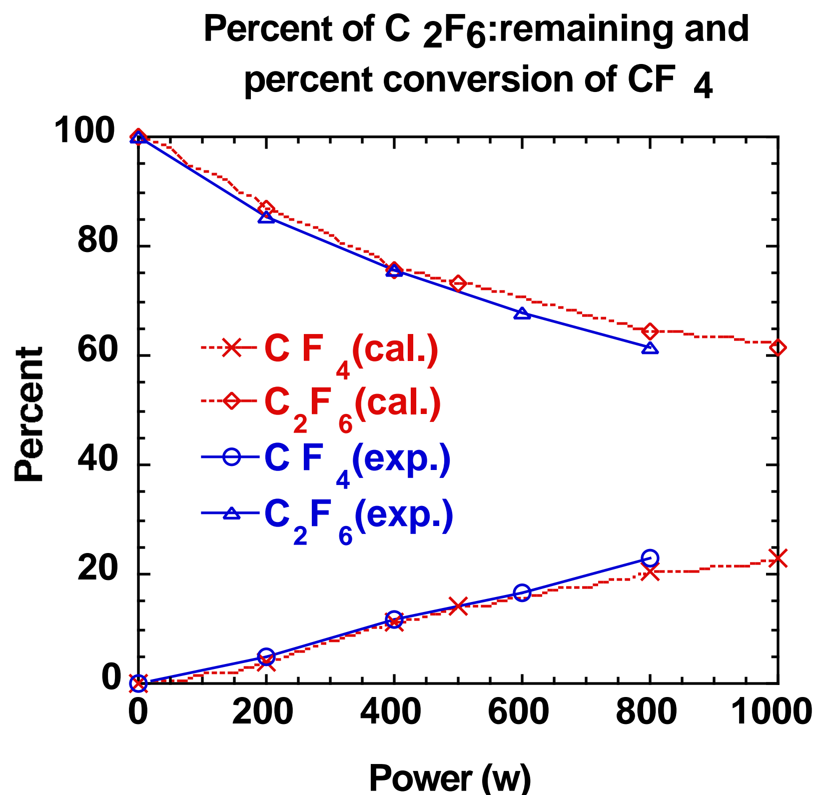
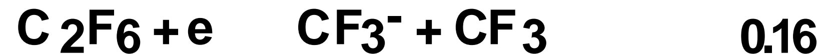
SIMULATION RESULTS FOR EXPERIMENTAL CONDITIONS



- C_2F_6: 200 sccm
- O_2: 200 sccm
- Pressure: 500 mTorr

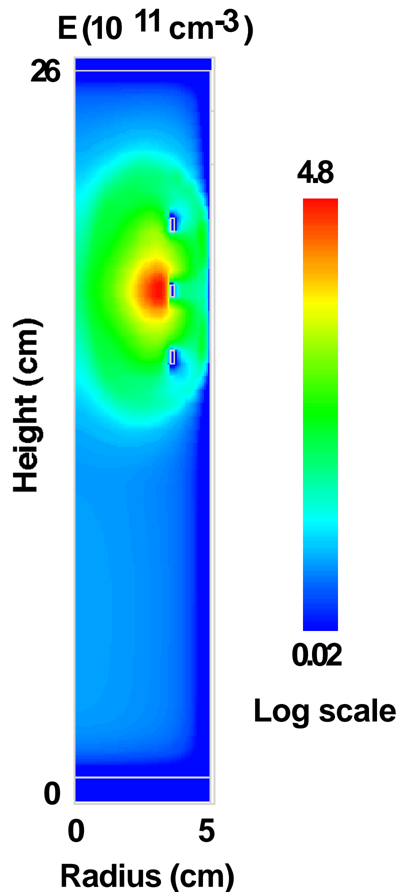
- The decomposition of C_2F_6 is mainly caused by electron impact.

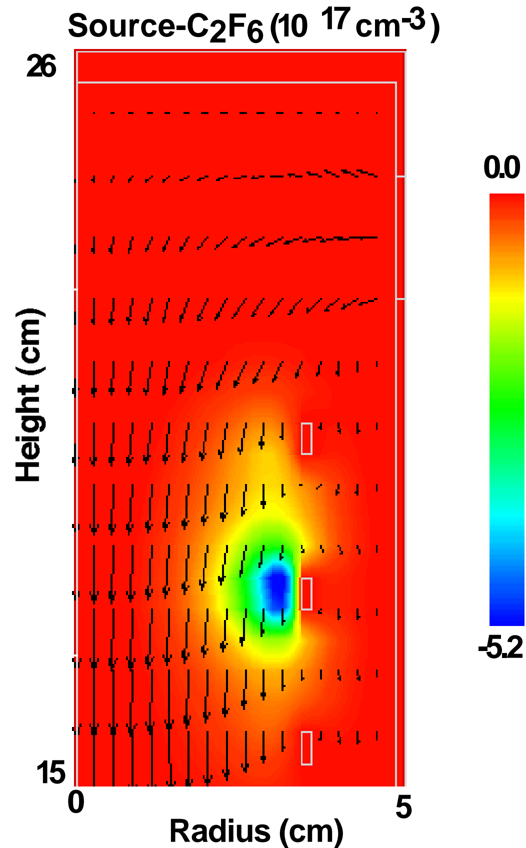


- The generation of CF_4 is via radical recombination. $CF_3 + F \quad CF_4$
- The formation of CF_4 depends on the gas temperature [$k=1.78 \cdot 10^{-8} \cdot (T/298)^{-7.73} \cdot \exp(-4271/T)\ cm^3 \cdot s^{-1}$] and the availability of F atoms to recombine with CF_3.
- The branching ratio for $C_2F_6 + e$ negative ions significantly changes the formation of CF_4.

SIMULATION RESULTS FOR ABATEMENT EXPERIMENT

- Plasma is generated only near the coils for 500 mTorr pressure due to the finite skin depth.
- Lower level of C_2F_6 decomposition is due, in part, to pass through of gases in center.





- C_2F_6: 200 sccm
- O_2: 200 sccm
- Pressure: 500 mTorr
- Power: 500 Watts

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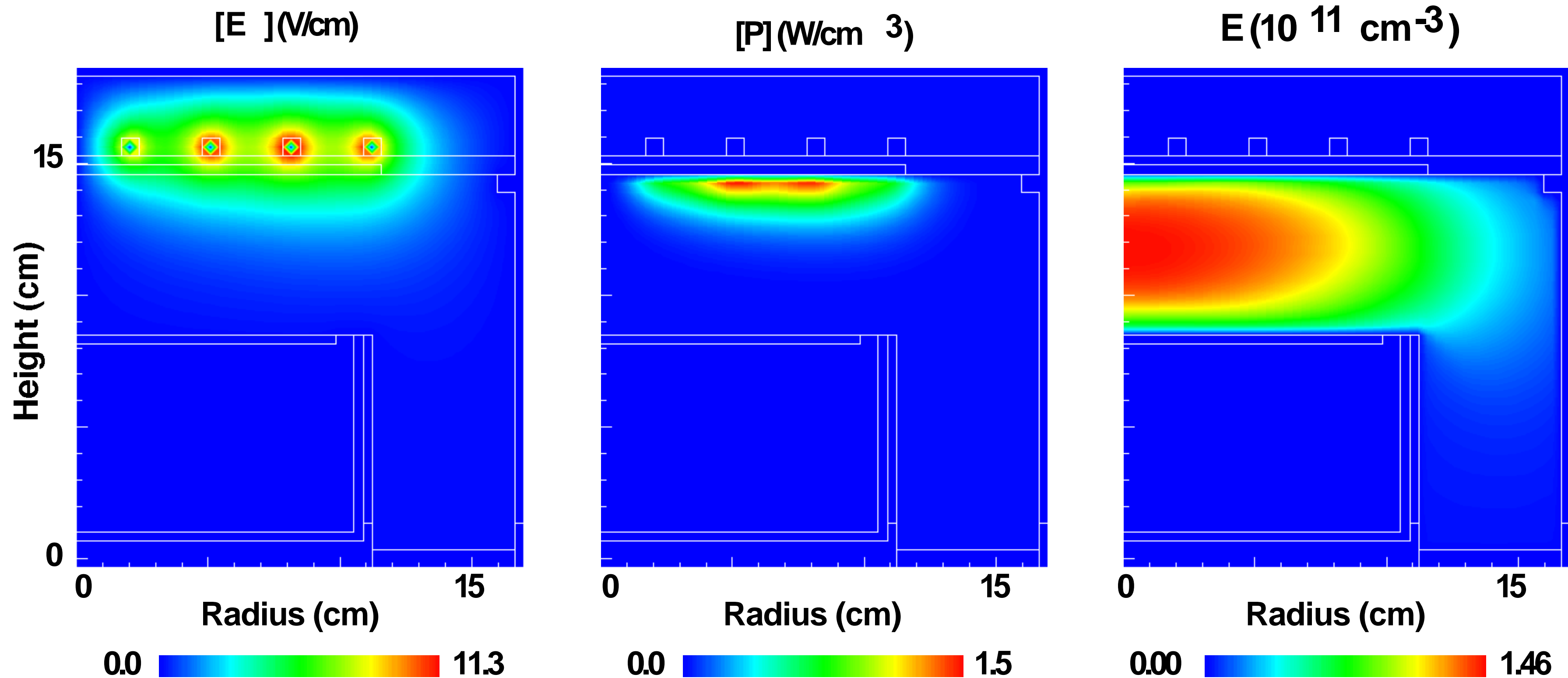
PLASMA PARAMETER IN ETCHING REACTOR

- A “standard” ICP reactor having a 4-turn coil is used as a baseline.
  - Power: 650 W
  - Gas flow: 200 sccm
  - Gas Mixture: Ar/C_2F_6 = 60/40
  - Pressure: 10 mTorr



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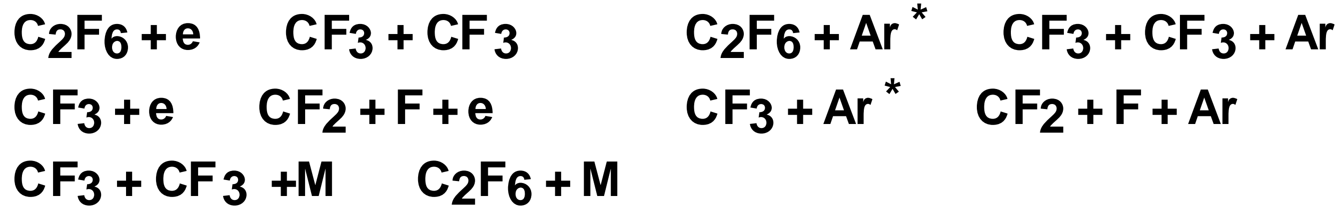
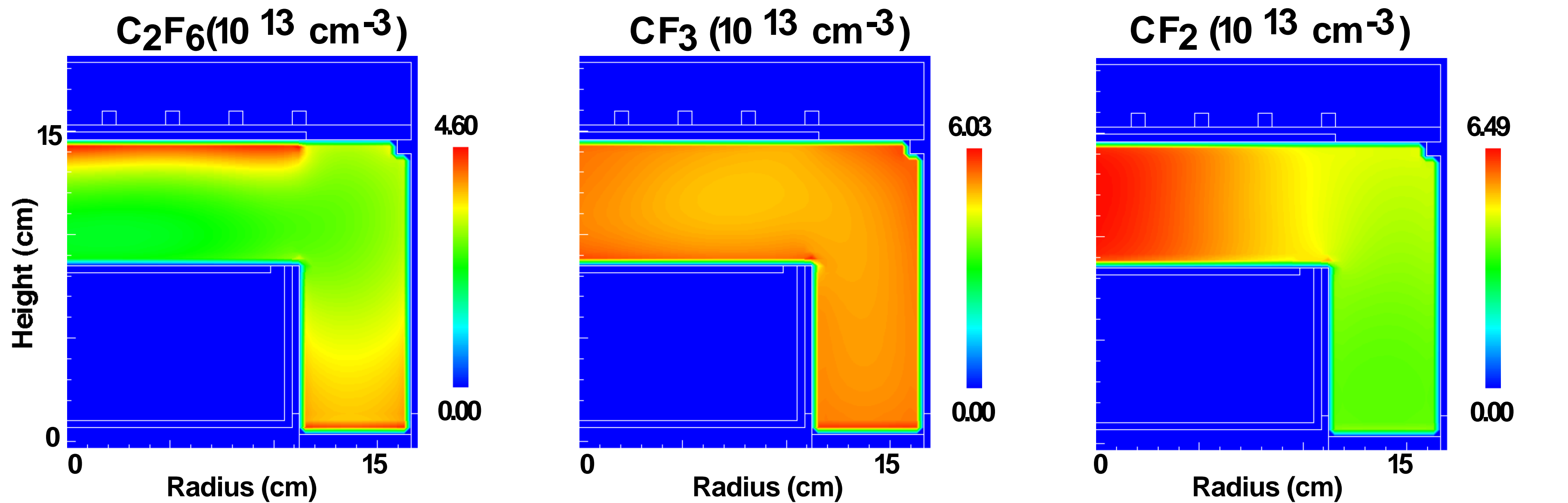
FEEDSTOCK NEUTRAL DISSOCIATION

- C_2F_6 can be dissociated mainly to CF_3, and CF_3 can be continuously dissociated to generate CF_2. Due to subsequent reassociation, the densities of C_2F_6 increase near pump port.





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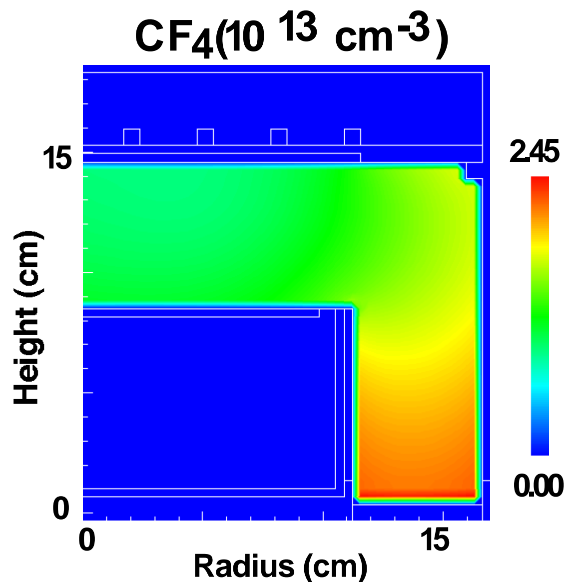
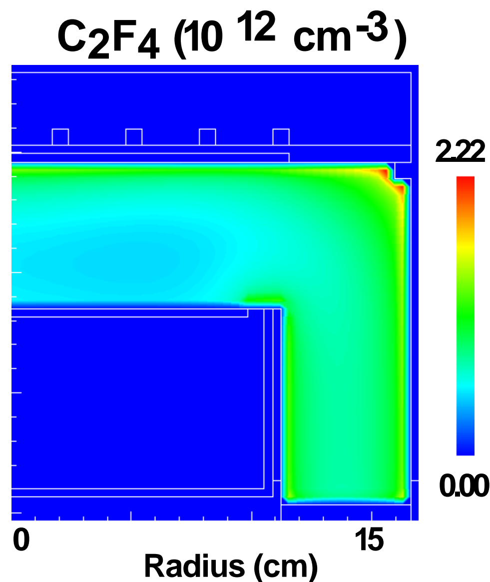
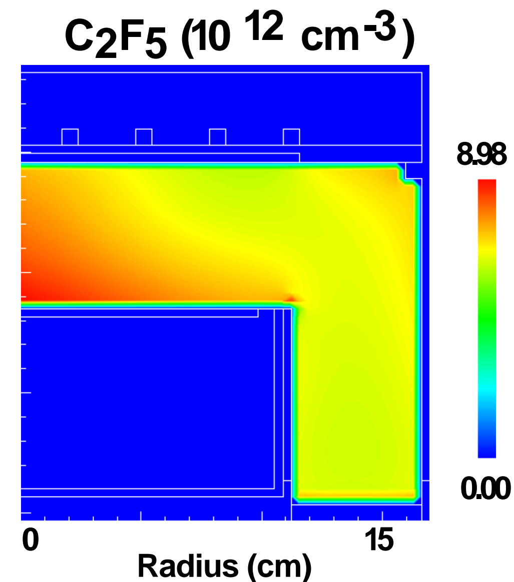
PFC GENERATION IN ETCHING CHAMBER

- Some PFCs are generated due to radical recombination.







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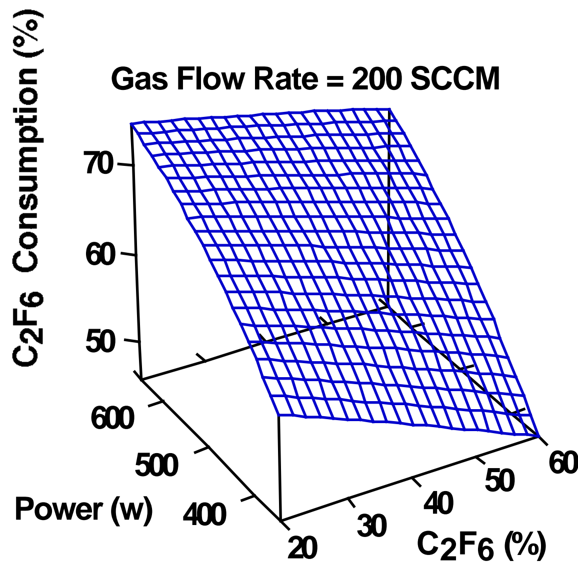
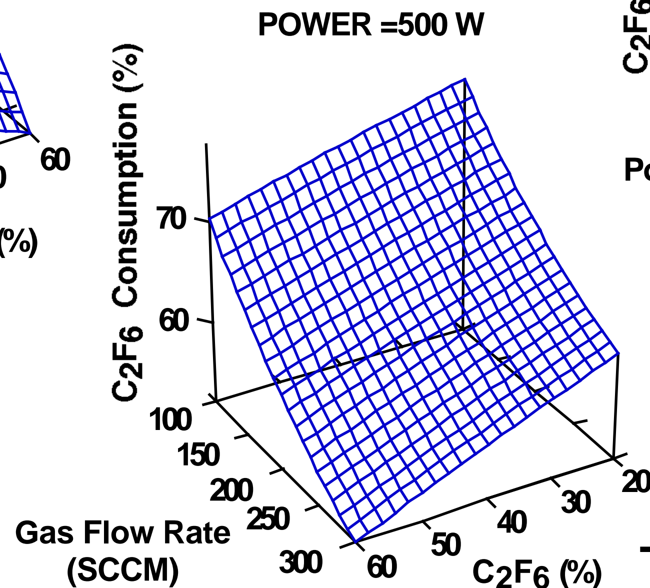
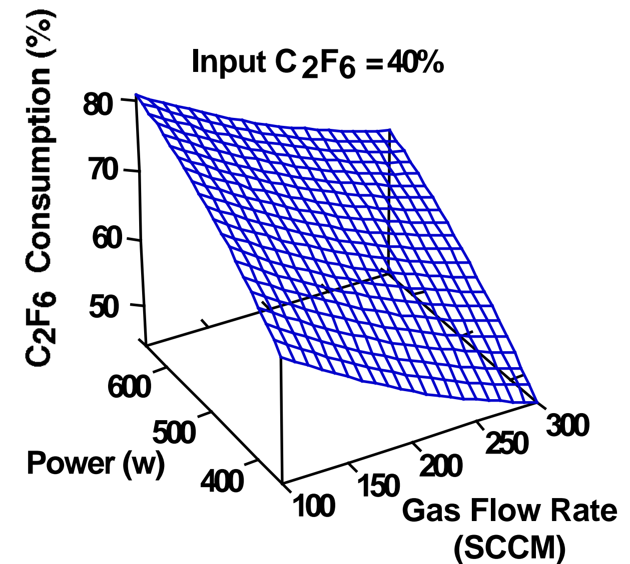
C_2F_6 CONSUMPTION IN ETCHING REACTOR

- A design of experiment has been performed to determine the functional relationships for C_2F_6 consumption.
- The consumption increases nearly linearly with a decrease in C_2F_6 percentage and gas flow rate, and with an increase of power deposition.





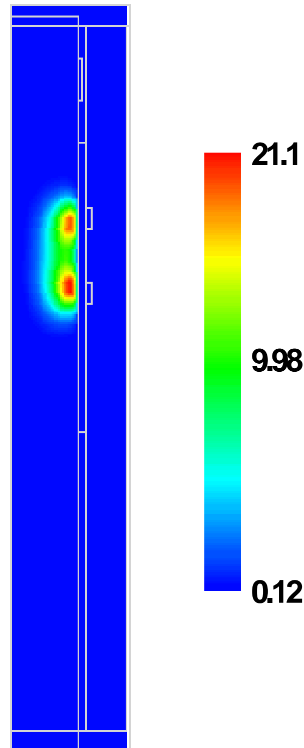


PLASMA PARAMETERS IN BURN BOX

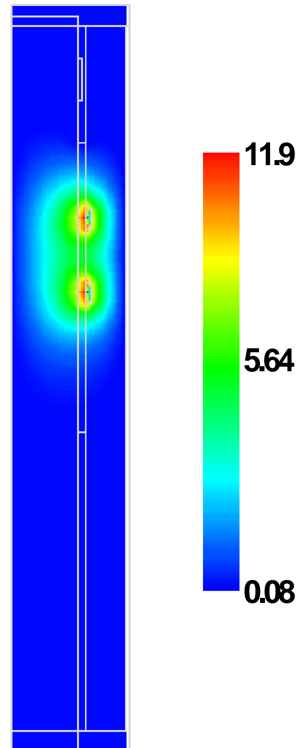
- A "standard" ICP burn box having a 2-turn coil with radius 4.25 cm and height 26.5 cm is used as a baseline.

- Power: 650 W
- Effluent: 227.7 sccm
- O_2 injection: 90 sccm
- Pressure: 150 mTorr

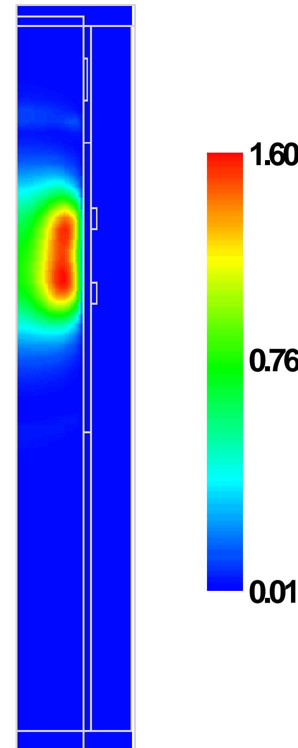
Power (W cm $^{-3}$)



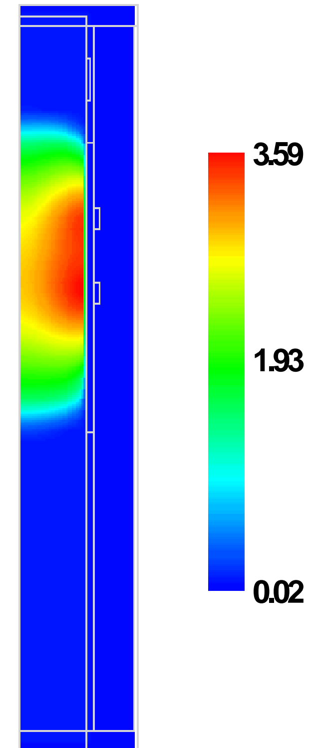
Electric field (V cm $^{-1}$)



E density (10^{12} cm $^{-1}$)



E Temperature (ev)



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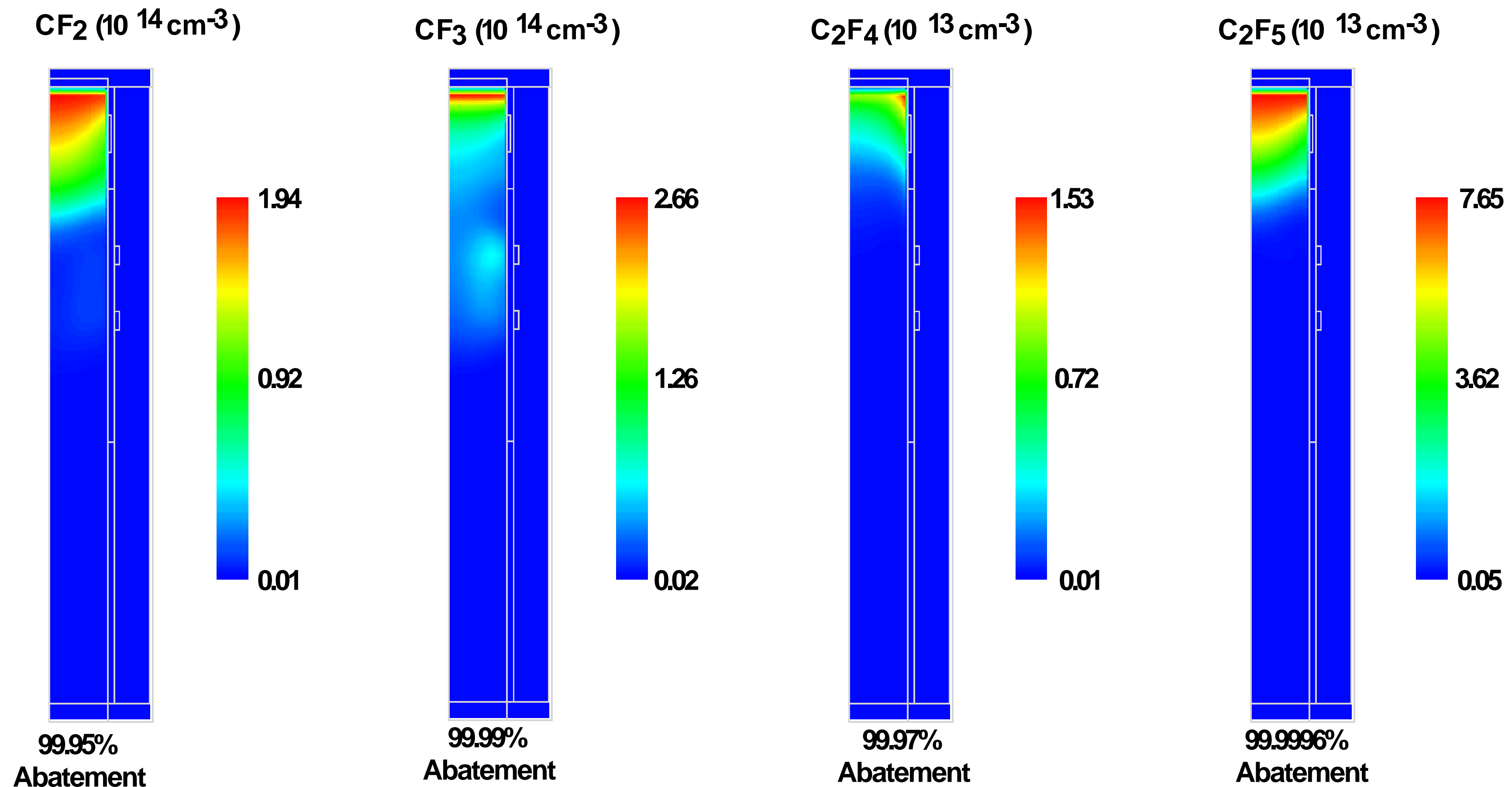
EFFLUENT C_mF_n REMOVAL IN PLASMA BURN BOX

- CF_2, CF_3, C_2F_4 and C_2F_5 from the etching reactor effluent are almost completely removed in the burn box.



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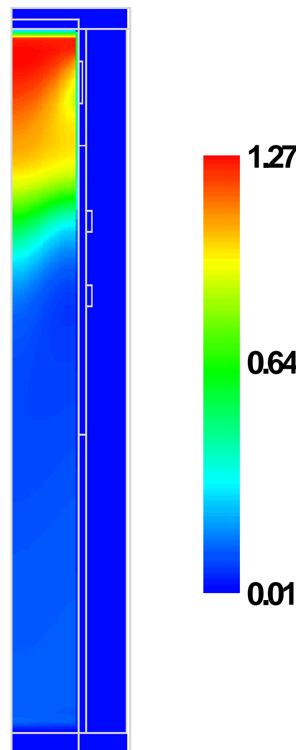
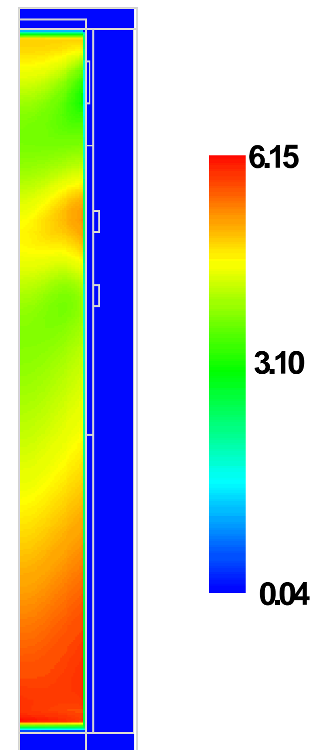
C_2F_6 ABATEMENT AND CF_4 GENERATION

- In the burn box, C_2F_6 in the etching reactor effluent is abated by 75%, but a significant amount of CF_4 can be generated (triple CF_4 in the effluent).

C_2F_6 (10^{15} cm^{-3})

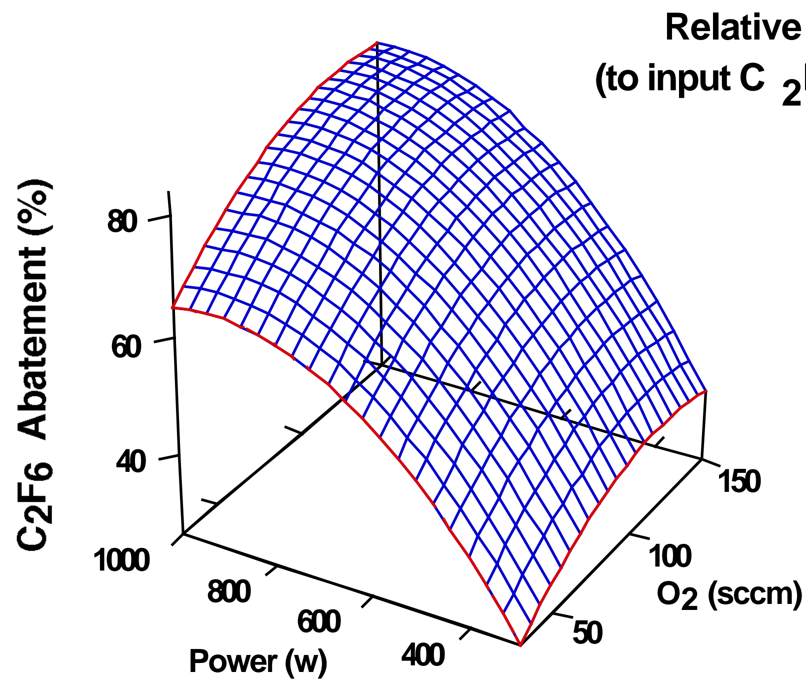


CF_4 (10^{14} cm^{-3})

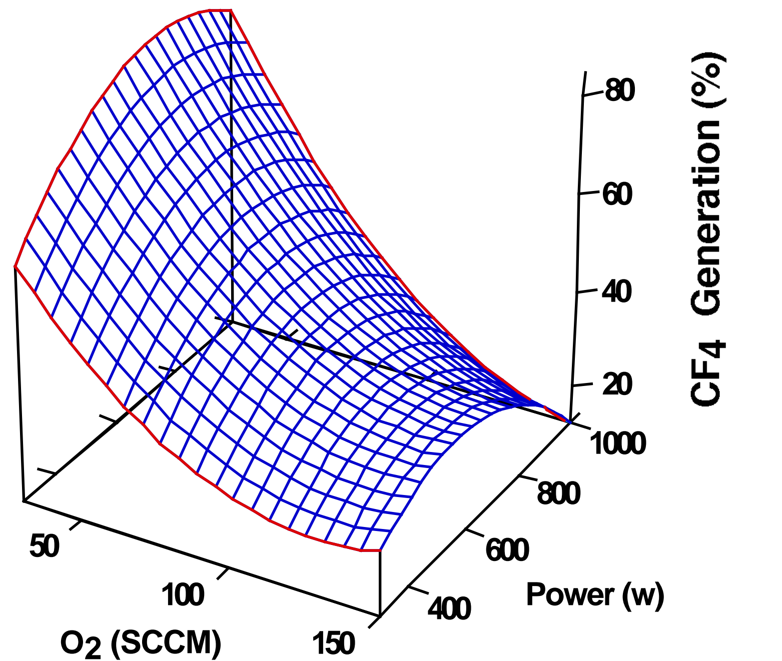


C_2F_6 ABATEMENT AND CF_4 GENERATION vs POWER, O_2

- C_2F_6 abatement increases with increasing power and O_2 fraction.
    - More dissociation of C_2F_6 CF_3, O_2 O
    - Subsequent reactions of O + CF_3
- CF_4 generation increases with increasing power and decreasing O_2. CF_4 is generated by the reaction of CF_3 + F. In O atom rich environments, CF_3 reacts to produce COF_2.



Relative Percent
(to input C_2F_6 amount)



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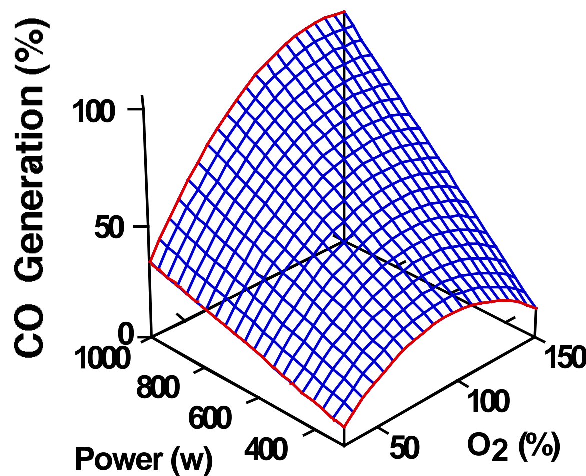
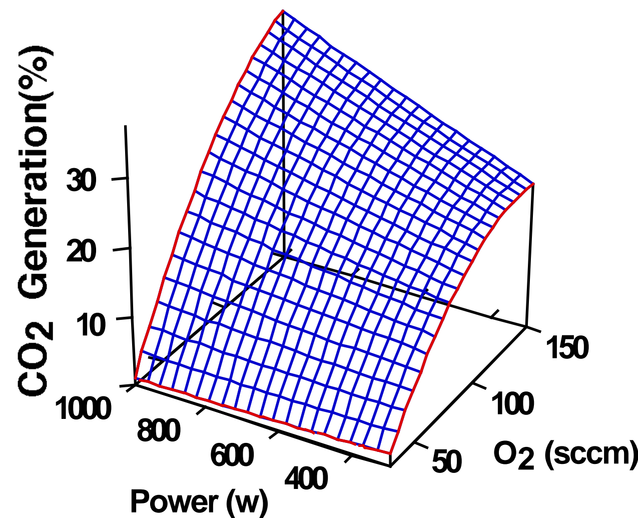
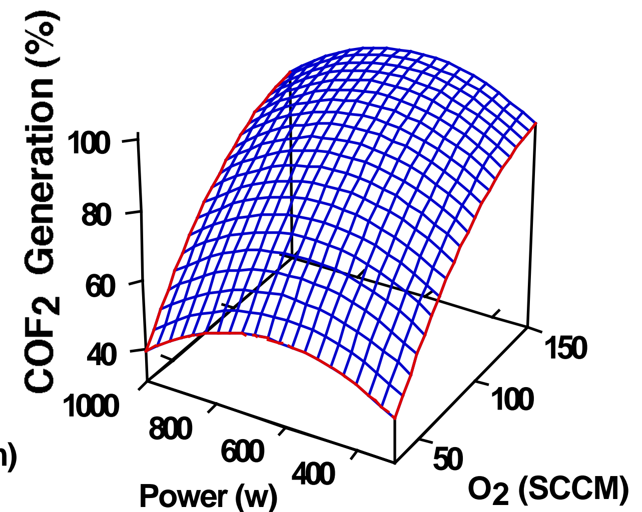
OXIDATION PRODUCT GENERATION vs POWER, O_2

- CO is preferentially formed at high power and high O_2 since CF_2 leads to CO. The sources of CF_2 and O are large at higher discharge power.
- CO_2 and COF_2 are preferentially formed at high O_2, however subsequent dissociation of CO_2 and COF_2 reduces this sensitivity.

Relative Percent (to input C_2F_6 amount)







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CONCLUSION

- PFC consumption and generation in an ICP plasma etching reactor, and PFC abatement in an ICP burn box have been discussed.

- C_2F_6 consumption for Ar/C_2F_6 gas mixtures in the etching reactor is proportional to ICP power deposition, and inversely proportional to C_2F_6 mole fraction and total gas flow rate.

- PFCs from the plasma etching effluent can be abated in the ICP burn box at high power and high O_2. With low O_2, C_2F_6 can be decomposed, however CF_4 is generated. The major oxidation products are CO_2, CO and COF_2.

- Low decomposition of C_2F_6 in can result from the finite electromagnetic skin depth resulting in "outside" power deposition and "pass through" of gases in the center.