ABATEMENT IN INDUCTIVELY COUPLED PLASMA REACTORS USING O_2, H_2 AND H_2O AS ADDITIVE GASES

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AGENDA

- Introduction
- Geometries of Etching Reactor and Burn Box
- Plasma Chemistry in Burn Box
- Validation
- Plasma Remediation of PFCs in Burn Box
- Concluding Remarks

INTRODUCTION

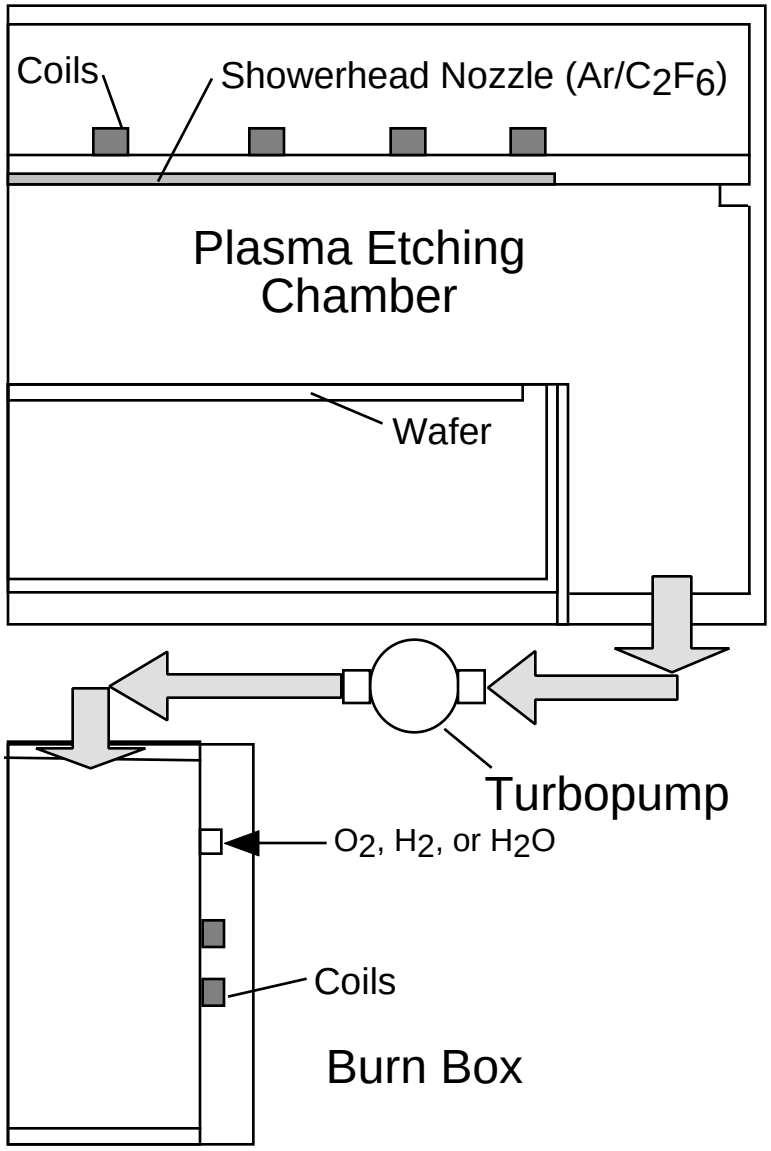
- Perfluorocompounds (PFCs), important process gases, are absorbers of infrared radiation having long atmospheric lifetimes and thus have high global warming potential.
- Since finding suitable substitutes for PFCs is unlikely, remediation of the effluent of plasma etching reactors must be done. Plasma remediation of gas emissions from plasma reactors is an attractive alternative abatement strategy.
- Efficient destruction of C_2F_6 as found in reactor effluent by plasmas has been experimentally demonstrated in low pressure devices.
- Computer modeling is a useful tool for investigating the physical processes occurring in plasma remediation of PFCs. It supplements the experiments and will be used to optimize the development of plasma unit designs.
- 2-D simulations of low pressure plasma remediation of PFCs have been performed.

PLASMA REMEDIATION FOR PFCS

- The effluent from the etching reactor having Ar/C_2F_6 = 40/60, 200 sccm and 350 W power deposition is used as input for the burn box.

Ar	0.306	C_2F_6	0.289
CF_3	0.173	CF_2	0.057
C_2F_4	0.011	C_2F_5	0.020
SiF_2	0.038	F	0.038
F_2	0.009		

Total flowrate is 227.7 sccm larger than the input flowrate due to dissociation.



OTHER CHEMISTRY IN BURN BOX

- Using H_2 or H_2O as an additive for PFC abatement, H and OH generated by electron impact dissociation become the primary species for abating CF_x radicals.
- H_2 and H_2O can also directly react with F, which thereby acts as a sink to remove free fluorine atoms which might otherwise recombine to form CF_4.

$$H + CF_3 \rightarrow CF_2 + HF$$
$$H + CF_2 \rightarrow CF + HF$$
$$H + CF \rightarrow C + HF$$
$$H_2 + F \rightarrow H + HF$$

$$OH + CF_3 \rightarrow COF_2 + F$$
$$OH + CF_2 \rightarrow COF + HF$$
$$OH + CF \rightarrow CO + HF$$
$$OH + CO \rightarrow CO_2 + HF$$
$$F + H_2O \rightarrow OH + HF$$

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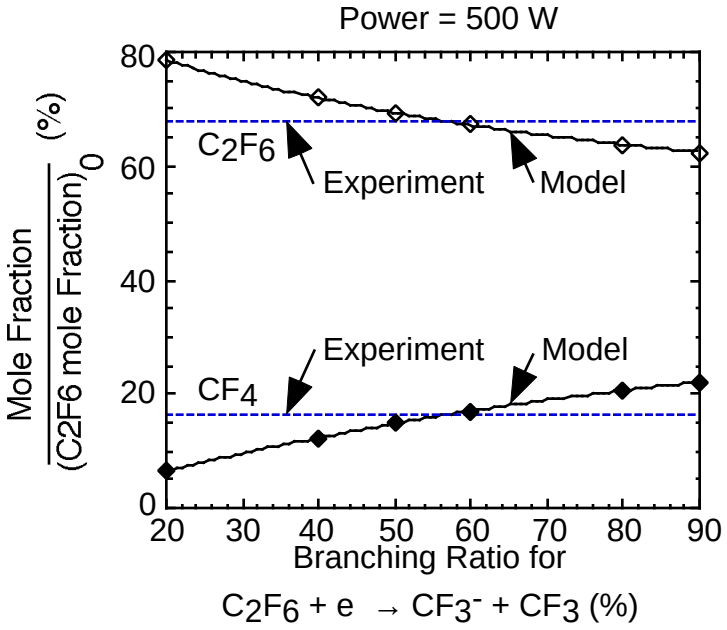
$$OH + CF_3 \rightarrow COF_2 + F$$
$$OH + CF_2 \rightarrow COF + HF$$
$$OH + CF \rightarrow CO + HF$$
$$OH + CO \rightarrow CO_2 + HF$$
$$F + H_2O \rightarrow OH + HF$$

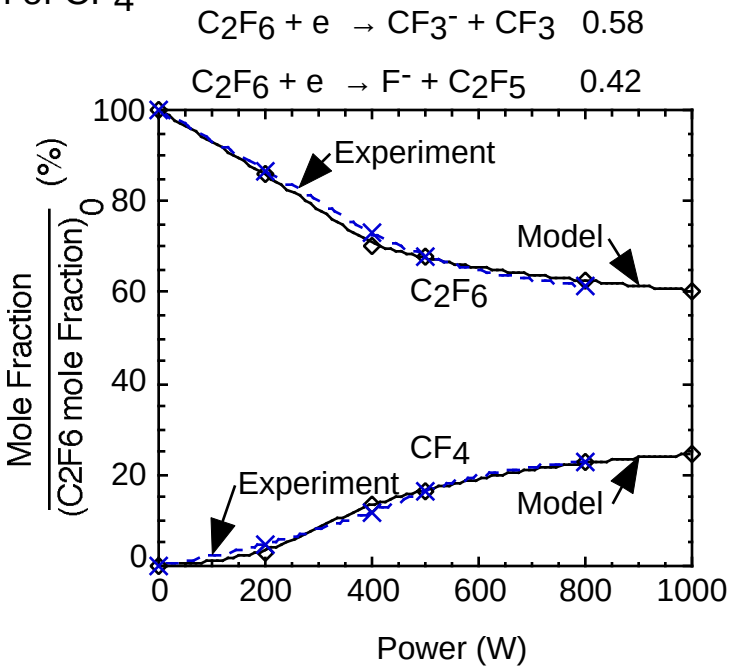
VALIDATION

- The model results were compared with the experimental results of Sawin and Vatile.

- The branching ratio for C_2F_6 + e → negative ions significantly changes the formation of CF_4.

Percent of C_2F_6 remaining and
percent conversion of CF_4



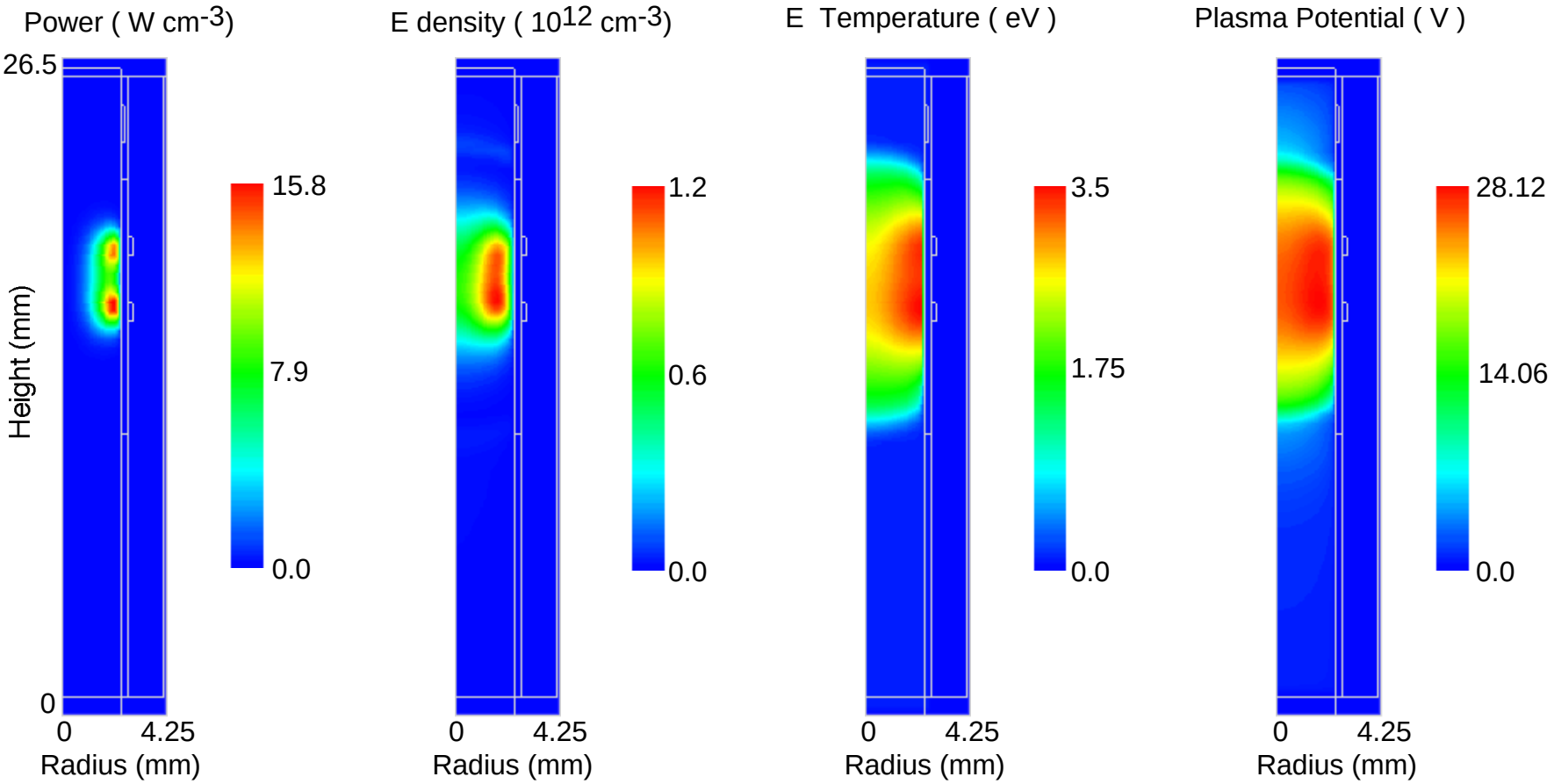


- C_2F_6: 200 sccm
- O_2: 200 sccm
- Pressure: 500 mTorr

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: 500 W
- Effluent: 227.7 sccm
- O_2 injection: 150 sccm
- Pressure: 150 mTorr



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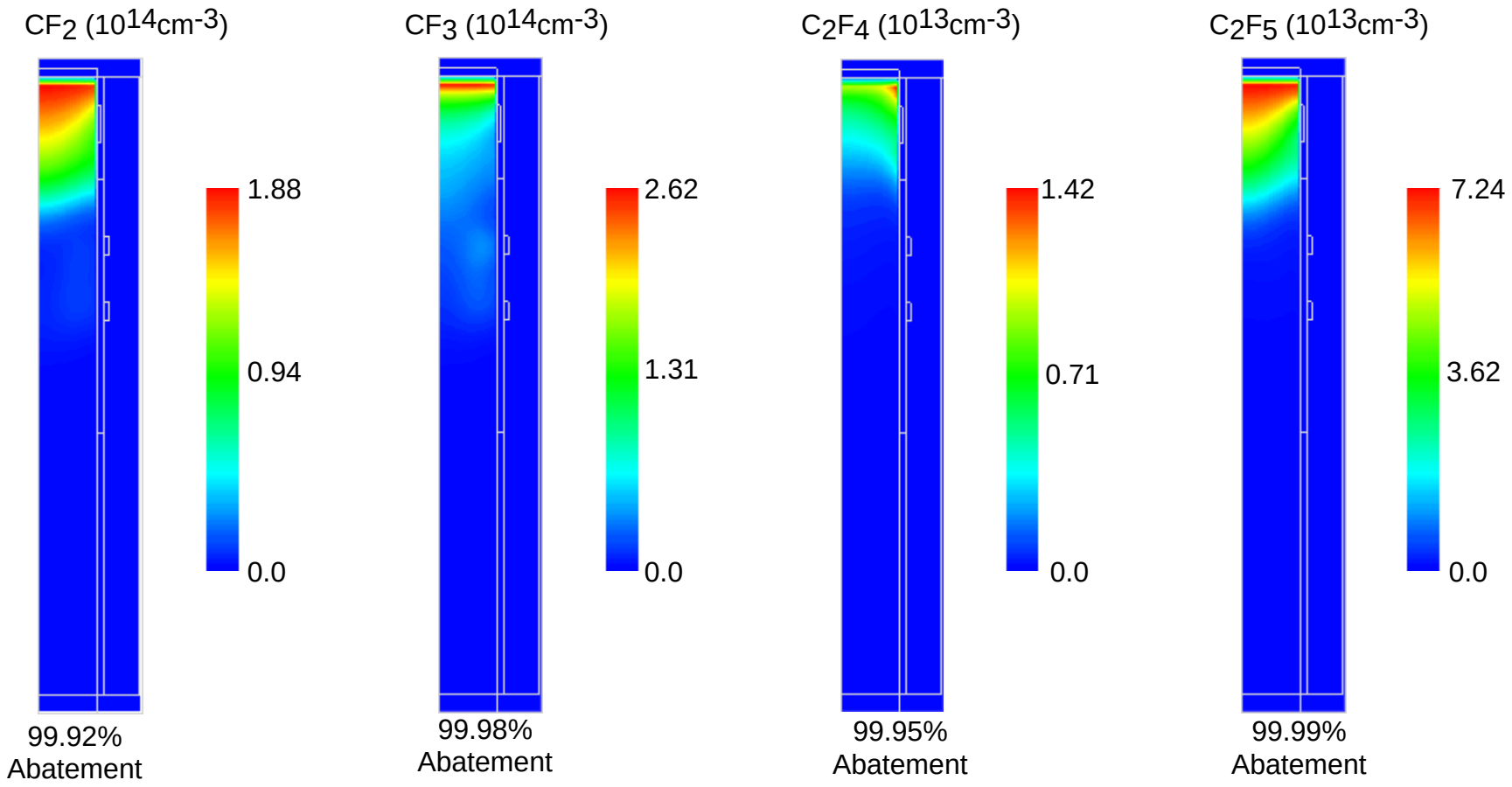
CxFy ABATEMENT IN PLASMA BURN BOX

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



- Power: 500 W
- O_2 injection: 150 sccm
- Effluent: 227.7 sccm
- Pressure: 150 mTorr

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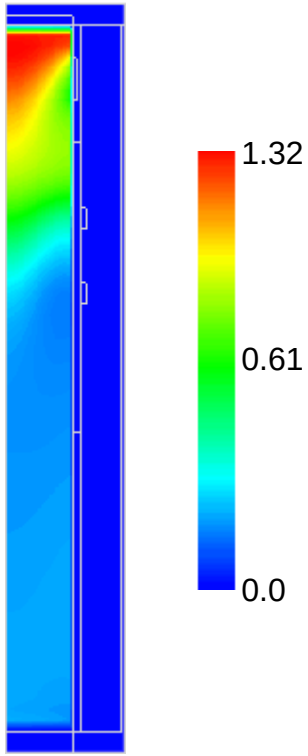
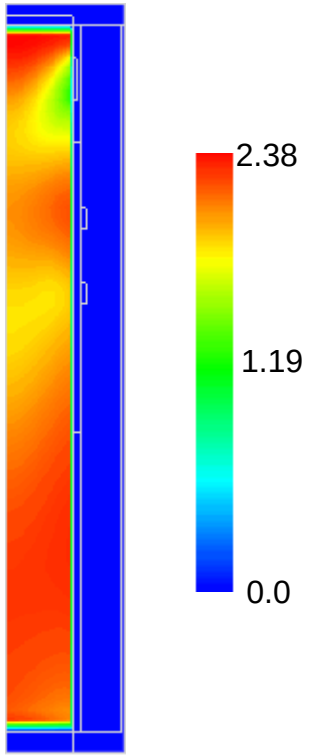
C_2F_6 ABATEMENT AND CF_4 GENERATION

- C_2F_6 in the etching reactor effluent is abated by 53%, but a significant amount of CF_4 can be generated (increased by a factor of 2.4).

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



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



- Power: 500 W
- O_2 injection: 150 sccm
- Effluent: 227.7 sccm
- Pressure: 150 mTorr

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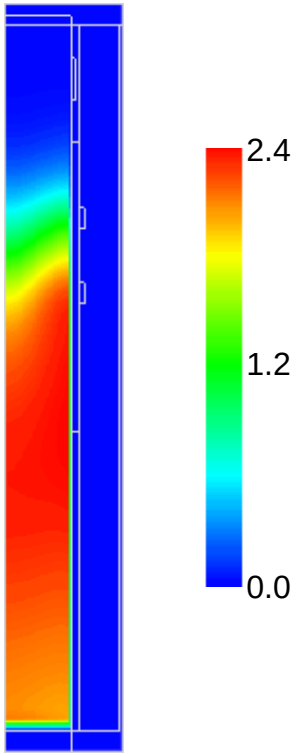
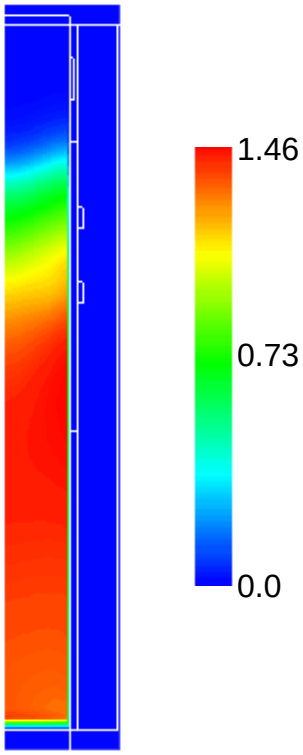
OXIDATION PRODUCTS IN PLASMA BURN BOX

- The major oxidation products are CO, CO_2, and COF_2 which can be removed by conventional methods.

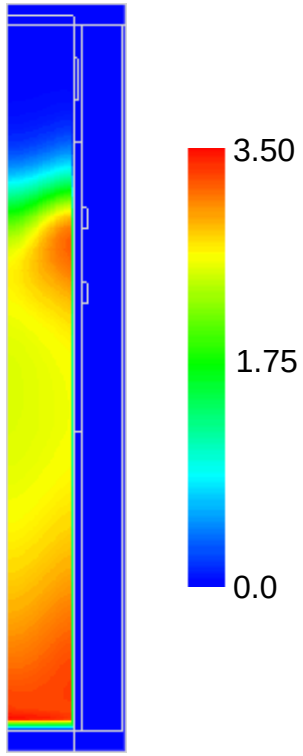
CO (10^{14} cm^{-1})



CO_2 (10^{14} cm^{-3})



COF_2 (10^{14} cm-1)



- Power: 500 W
- O_2 injection: 150 sccm
- Effluent: 227.7 sccm
- Pressure: 150 mTorr

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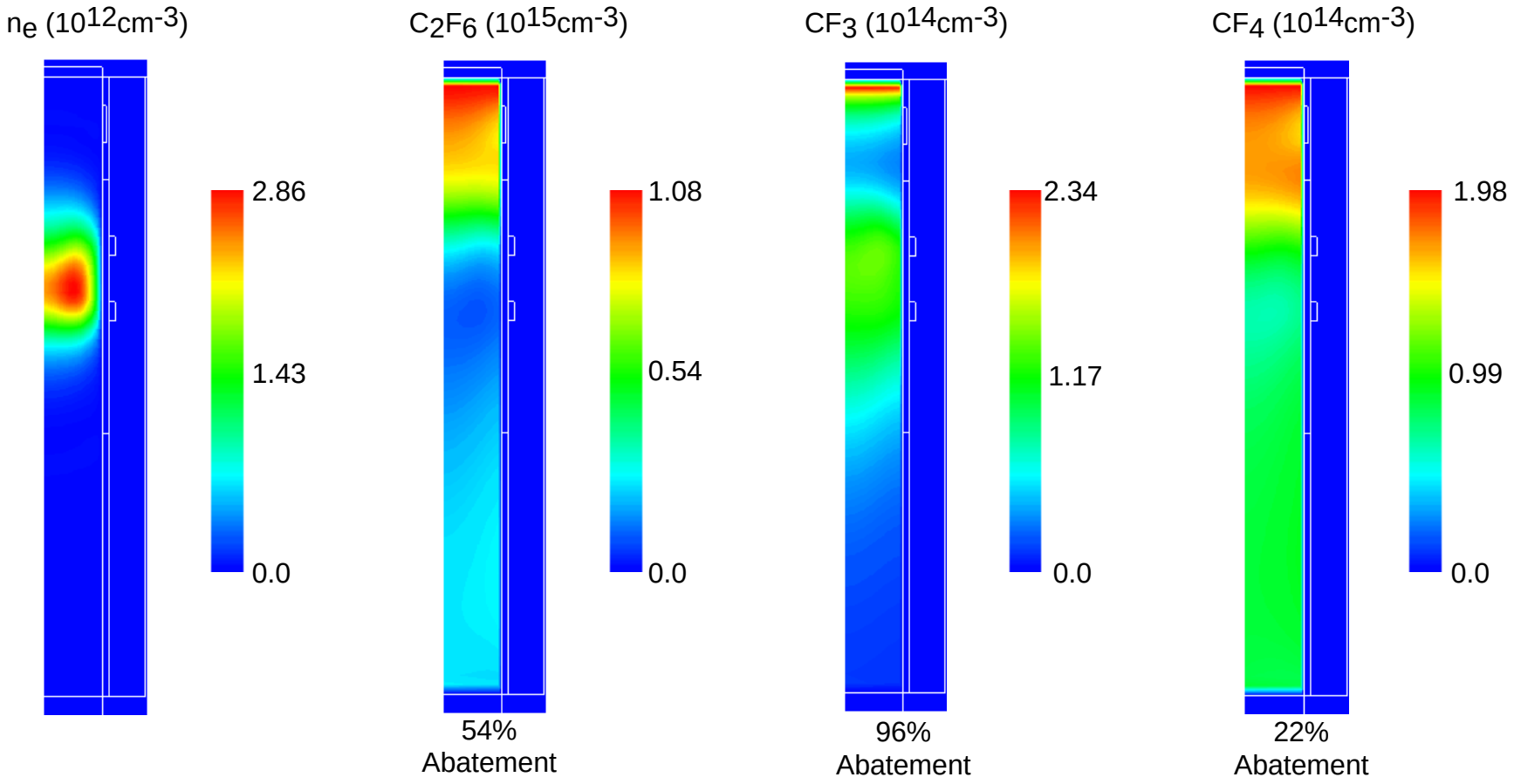
SPECIES DENSITY USING H_2 AS AN ADDITIVE

- Compared to the O_2 case, the electron density is increased by a factor of 2.4 due to the lower rate of attachment to H_2.
- C_2F_6, CF_3, and CF_4 are abated in the burn box.



- Power: 500 W
- H_2 injection: 150 sccm
- Effluent: 227.7 sccm
- Pressure: 150 mTorr

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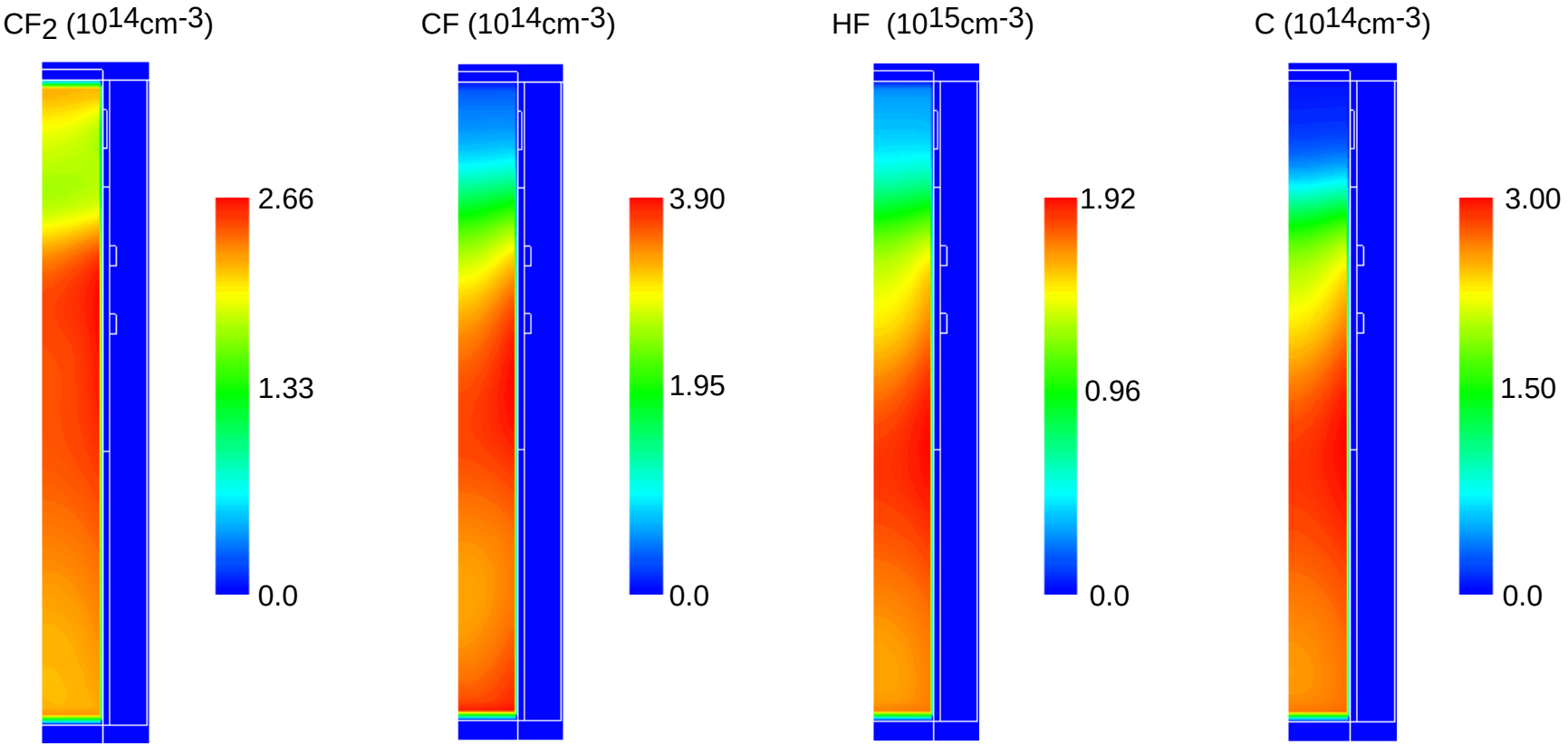
PRODUCTS USING H_2 AS AN ADDITIVE

- HF is the major product (0.49) leaving the burn box with lesser amounts of CF (0.094), C (0.074) and CF_2 (0.041).
- The higher mole fraction of CF and CF_2 compared to O_2 are due to there being insufficient H to reduce them to C.



- Power: 500 W
- H_2 injection: 150 sccm
- Effluent: 227.7 sccm
- Pressure: 150 mTorr

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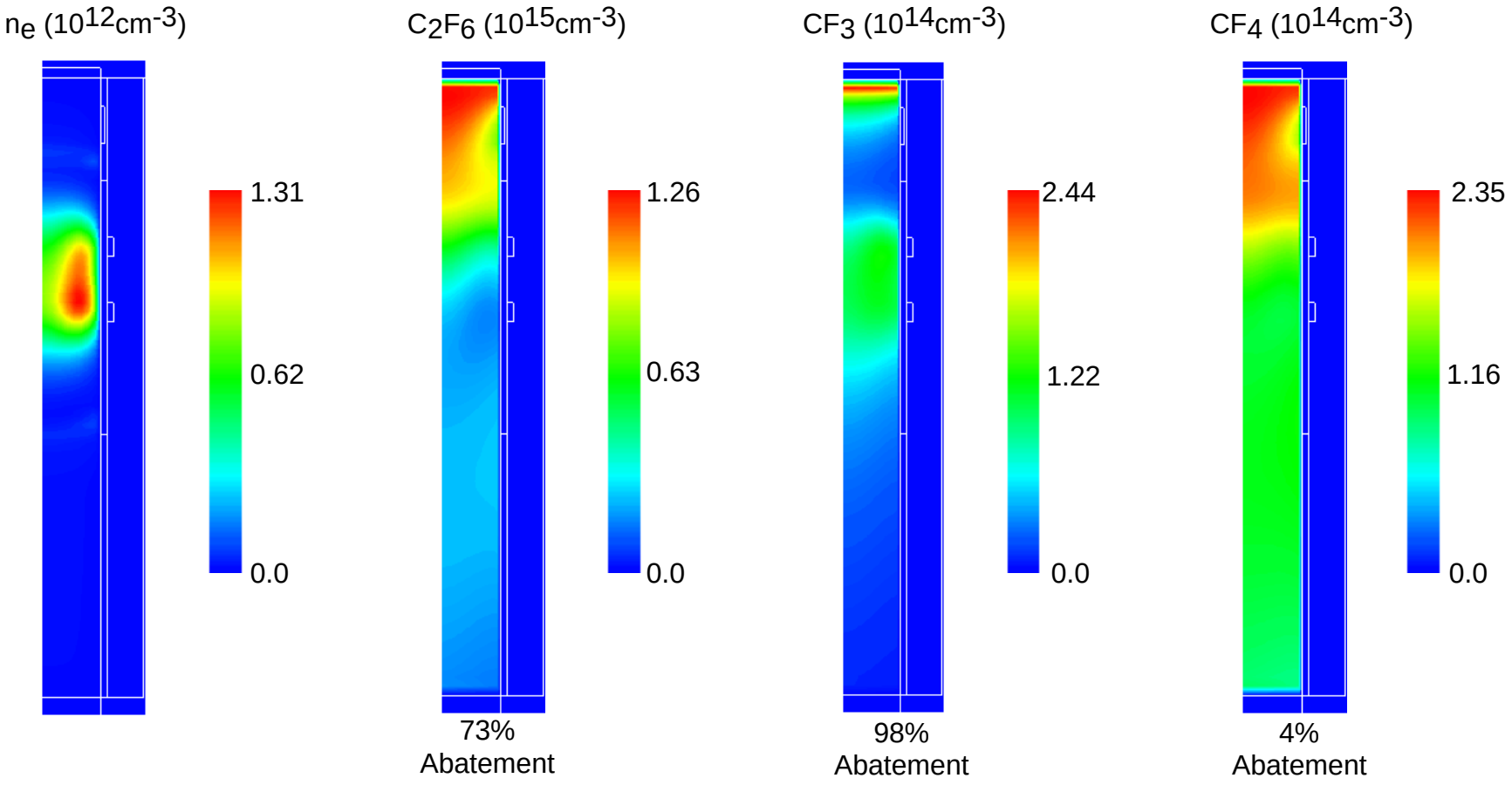
SPECIES DENSITY USING H_2O AS AN ADDITIVE

- The electron density is higher than the base case with O_2 as an additive, but lower than for H_2, due largely to the rate of attachment of H_2O being between O_2 and H_2.



- Power: 500 W
- H_2O injection: 150 sccm
- Effluent: 227.7 sccm
- Pressure: 150 mTorr

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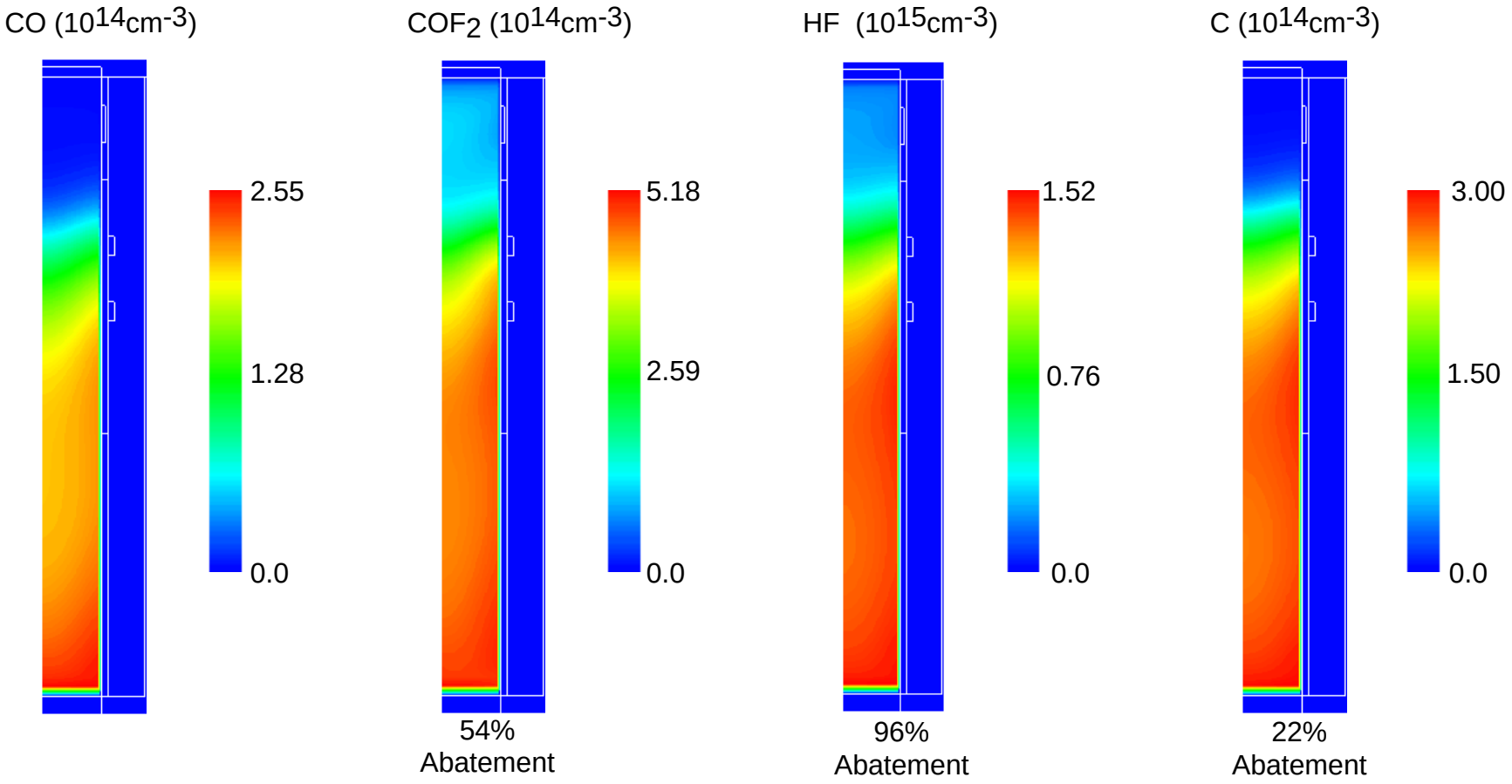
PRODUCTS USING H_2O AS AN ADDITIVE

- Using H_2O as an additive, the major products are HF, COF_2, CO and C.
- The F atoms which were initially bound in all C_xF_y were converted to products in the proportions: HF, 59.8, and COF_2, 40%. The carbon atoms initially bound in C_xF_y were converted to products in COF_2, 63.3%; CO, 3.4%; C, 3.9%; and CO_2 1.4%.



- Power: 500 W
- H_2O injection: 150 sccm
- Effluent: 227.7 sccm
- Pressure: 150 mTorr

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ABATEMENT USING O_2, H_2, OR H_2O AS AN ADDITIVE

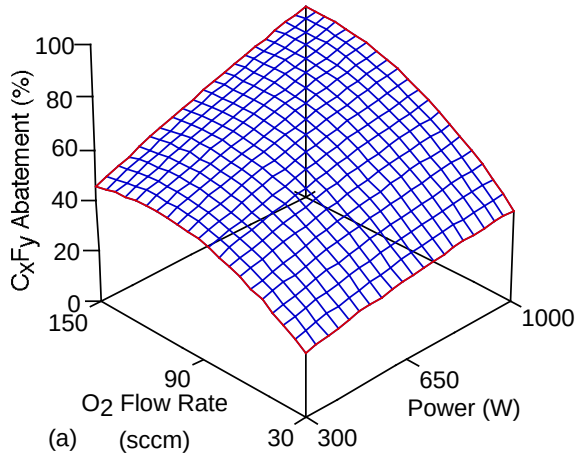
- Abatement of each C_xF_y species and total PFC species, primary products, W value of all C_xF_y using 150 sccm O_2, H_2, or H_2O as additives at 500 W

Species	Fractional Abatement for Additives $\frac{\text{Initial - Final}}{\text{Initial}}$		
	O_2 Additive	H_2 Additive	H_2O Additive
C_2F_6	0.53	0.54	0.73
C_2F_5	>0.99	-0.47	0.37
C_2F_4	>0.99	-2.71	-0.31
C_2F_3	>0.99	0.22	0.35
CF_4	-1.4	0.23	0.04
CF_3	>0.99	0.96	0.98
CF_2	>0.99	-0.4	0.05
Products	COF_2, CO_2, CO, F, F_2	HF, , C, CF	HF, COF_2, CO_2, CO, C, CF
η of C_xF_y	0.54	0.42	0.65
W Value (ev)	124.9	159.8	119.3

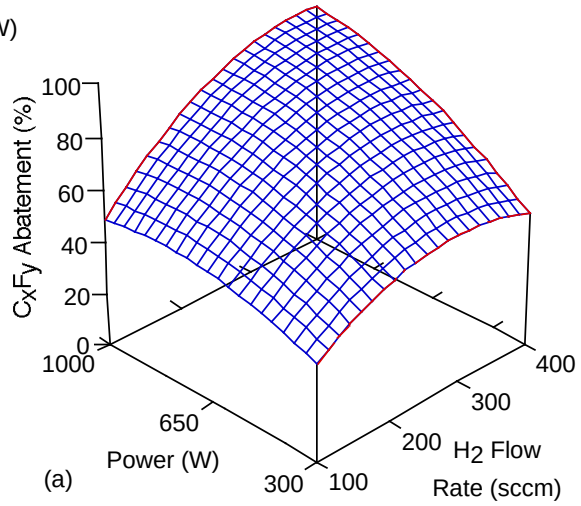
FRACTION OF C_xF_y ABATEMENT

- The fraction of C_xF_y abatement increases with increasing power deposition and the amount of addictive gases.

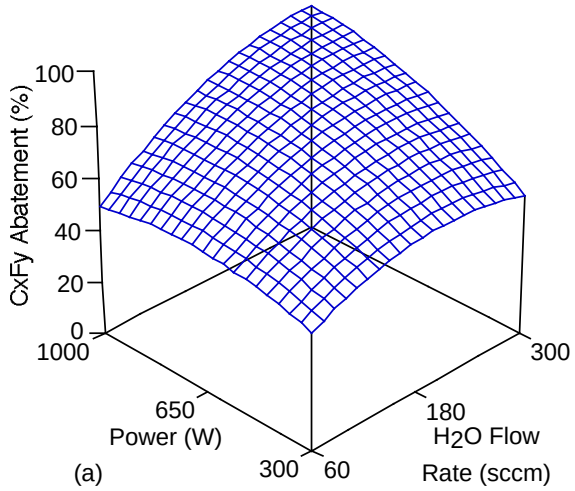
Additive O_2



H_2 Additive



Additive H_2O



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W-VALUE FOR C_xF_y ABATEMENT

- The W-value increases (lower power efficiency) with increasing power deposition decreasing the amount of addictive gases.

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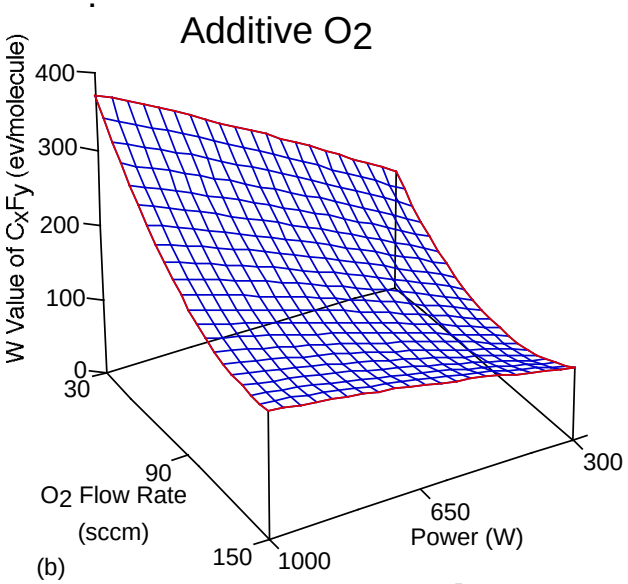

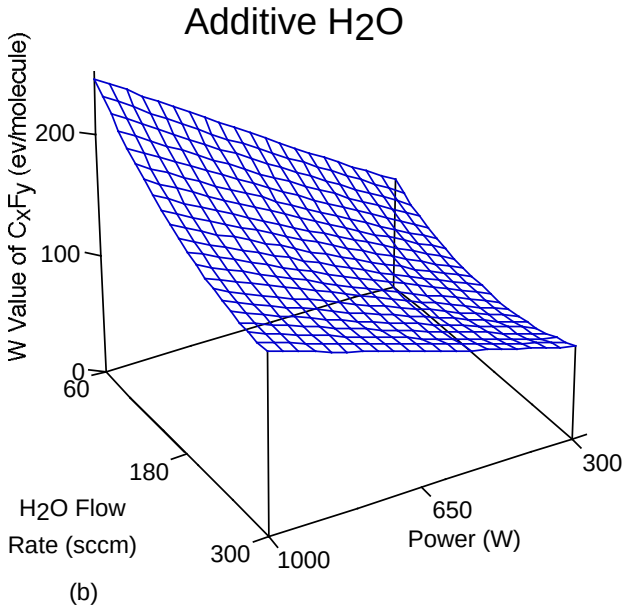

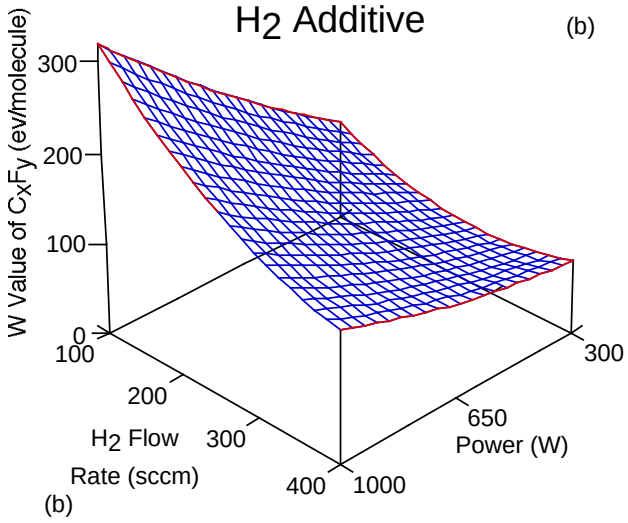

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CONCLUSIONS

- The model was validated by comparison to experiments using O_2/C_2F_6.
- PFCs from plasma etching effluent can be efficiently destroyed in ICP burn box.
- In general, CF_4 generation occurs during abatement of C_2F_6 using O_2 as an additive. The major oxidation products are COF_2, CO and CO_2.
- H_2 can be used as an alternative to O_2 without producing CF_4 since hydrogen reacts rapidly with free fluorine which otherwise reassociateswith $CF_x$to form CF_4. F and C atoms initially contained in C_xF_y were converted to HF and C.
- H_2O is a promising and efficient abatement additive gas since it has a source of both oxygen and hydrogen. The primary products are HF, CO, COF_2 with a small amount of C and CO_2.