The Use of C₄F₆ for Dielectric Etch with Reduced Global Warming Emissions

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Agenda

- Unsaturated Fluorocarbons and C\textsubscript{4}F\textsubscript{6}.
- Experimental.
- Process and emissions performance.
- Conclusions.
- Future work.
Unsaturated Fluorocarbons Tested

- octafluoro-2-butene ($C_4F_8$, $CF_3-CF=CF-CF_3$) (OF2B)
- hexafluoropropene ($C_3F_6$, $CF_2=CF-CF_3$)
- octafluorocyclopentene ($c-C_5F_8$)
- hexafluorobenzene ($C_6F_6$)
- hexafluorocyclobutene ($c-C_4F_6$)
- hexafluoro-1,3-butadiene ($C_4F_6$, $CF_2=CF-CF=CF_2$) (HF13B)
- hexafluoro-2-butyne ($C_4F_6$, $CF_3-C≡C-CF_3$) (HF2B)
Best Emissions Reduction for Each UFC
C₄F₆ Isomers

Hexafluoro-2-butyne
Boiling Point: -25 C
TSCA listed

Hexafluorocyclobutene
Boiling Pt: 1 C
Not TSCA listed

Hexafluoro-1,3-butadiene
This is the AMAT Sifren46 isomer
Boiling Point: 7 C
TSCA listed
Experimental

- All processes run on inductively coupled high density plasma etch chamber on patterned wafers with via test structures.
- Via etch process performance assessed by cross sectional scanning electron microscopy (SEM).
- Emissions measured using Fourier transform infrared (FTIR) spectrometer with 10 cm cell.
  - Effluents monitored: CF$_4$, CHF$_3$, C$_2$F$_6$, C$_3$F$_8$, C$_2$F$_4$, SiF$_4$, HF, CO, CO$_2$, COF$_2$, and the etch gas used.
Experimental (cont.)

- Metric for reporting Global Warming Emissions:
  \[
  kgCE = \sum_i Q_i \times \frac{12}{44} \times GWP_{100i}
  \]
  where \(i\) indexes each gas, \(Q_i\) is the quantity in kg of each gas, and \(GWP_{100i}\) is the global warming potential of each gas.

- Process of comparison is a typical \(C_3F_8\) based process:
  Emissions = 0.316 kgCE ; Via Depth = 0.8411 \(\mu m\)
Process Results: HF13B

Process Conditions:
- 1000 W Bias Power
- 2160 W Source Power
- 27 sccm HF13B Flow
- 75 sccm Ar Flow
- 6 mTorr Pressure
- 160 C Roof Temperature
- 120 s Etch Time

Recent accomplishment:
No need for O\(_2\) in process. This leads to a greater process control as the etch rate and resist selectivity strongly depends on O\(_2\) flow.

Low roof and wall temperatures lead to greater process kit longevity.
FTIR Spectra for HF13B Process

- HF
- CO
- CF₄
- CHF₃
- C₂F₆
- SiF₄
- C₂F₄

Thrust A Teleconference - December 7, 2000
Emissions Results: HF13B

Significantly more $\text{C}_2\text{F}_4$ being produced than $\text{C}_2\text{F}_6$, $\text{CF}_4$, $\text{C}_3\text{F}_8$, or $\text{CHF}_3$.

Total Emissions: 0.0628 kgCE
Reduction: 82.1%
HF13B Destruction Efficiency: 99.5%
Process Results: HF13B

The breakthrough step is a less selective etch needed to breakthrough the silicon oxynitride ARC layer.

Breakthrough step:
1000 W Bias Power
1936 W Source Power
10 sccm HF13B Flow
75 sccm Ar
25 sec

Etch step:
1000 W Bias Power
1936 W Source Power
22 sccm HF13B Flow
75 sccm Ar
6 mTorr Pressure
160 C Roof Temperature
90 sec
Process and Emissions Results: HF2B

Total Emissions: 0.0539 kgCE
Reduction: 82.9%
HF2B Destruction Efficiency: 99.3%

Process Conditions:
1000 W Bias Power 1680 W Source Power
24 sccm HF2B Flow 75 sccm Ar Flow
6 mTorr Pressure 160 C Roof Temperature
120 s Etch Time
Components of the Emissions: HF2B

![Graph showing molar emissions of various components for C3F8 and HF2B.](image-url)
Process and Emissions Results: c-C4F6

Total Emissions: 0.0774 kgCE
Reduction: 75.5%
c-C4F6 Destruction Efficiency: 98.5%

Process Conditions:
800 W Bias Power 1920 W Source Power
24 sccm c-C4F6 Flow 75 sccm Ar Flow
6 mTorr Pressure 160 C Roof Temperature
120 s Etch Time
Conclusions

• Developed etch processes based on three isomers of C₄F₆ and compared to a typical C₃F₈ based process.
  – Low/no resist erosion
  – Comparable etch rates and feature profiles
  – >80% global warming emissions reduction

• Processes are simple with only C₄F₆ and carrier gas as inputs.

• Emissions reduction is a result of high production of C₂F₄ rather than CF₄ as well as no impact of unreacted etch gas.
Future Work

- Examine selectivity of these chemistries to common stop layers.
- Evaluate the performance in a medium density plasma environment.
- Examine the process and emissions performance on common low-k dielectric etch applications.
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