Wet-Burn-Wet Abatement Evaluation on 300mm Silicon Nitride Deposition

SESHA Conference 2017
Agenda Outline

• Introduction and Objectives
• Test Setup and Timeline
• Chamber Cleaning Test Results
• Deposition Process Test Results
• Discussion
• Questions
Introduction and Objectives
Silicon Nitride Deposition

- Silicon Nitride is typically used in semiconductors as a dielectric, oxidation mask or a passivation layer

$$3\text{SiH}_4 + 4\text{NH}_3 \rightarrow \text{Si}_3\text{N}_4 + 12\text{H}_2$$

- Process flows also include a carrier gas and possibly N2O

- As required, removal of deposits from tool reaction chamber walls requires a chamber cleaning step often through flows of NF3 and carrier gases
Burn-Wet Operation Summary

SiN – Dep Process Abatement

Gases Put Into Burner
- SiH₄
- NH₃

Process Step
- C₂F₆/NF₃
- HF/F₂
- SiF₄

Dry Wall Burner

Post Burn Wet

Burner Output
- Si-Deposits
- Si-particles
- NH₄F Sub-μ particles
- High NOₓ
- HF
Wet-Burn-Wet Operation Summary

SiN – Dep Process Abatement

Gases Put Into Burner
- SiH4

Process Step
- C2F6/NF3

Clean Step

Wet Wall Burner

Pre Burn Wet
- Removed by Pre Wet
- NH3
- HF/F2
- Chamber clean byproducts

Post Burn Wet

Burner Output
- SiO2- Particles
- NH4F Particles (reduced)
- No Excess NOx
- From NH3 Burn HF
Project Scope

• Evaluate an Airgard Encompass wet-burn-wet abatement unit for performance against currently installed TPU-4 burn-wet abatement unit
  – Remove ammonia prior to house exhaust system
  – Concerns regarding excess ammonium fluoride particulates
  – Concerns regarding excess NOx generated due to ammonia

• Further concerns regarding Greenhouse Gas Destruction
  – NF3 DRE
  – N2O DRE and effects on NOx
  – Performance with CDA and O₂

• Reliability and maintenance of unit
Test Setup and Timeline
Testing Method

- Extractive Fourier Transform Infrared (FTIR) Spectroscopy

- Procedures were consistent with EPA Protocol for Measuring Destruction or Removal Efficiency of Fluorinated Greenhouse Gas Abatement Equipment in Electronics Manufacturing (March 2010)

- Data was gathered using Method 2, “Total Volume Measurements”, which measures DREs under actual process conditions where byproducts are formed and analytical determined influent/effluent exhaust flows were performed via process NF$_3$ or SF$_6$ tracer gas injection
Timeline for Encompass Testing (Day 1)

MFC NF₃ Metered Flows
1000 sccm, 750 sccm, 500 sccm,
Plasma Off, for Influent Flow
Determinations via FTIR

FTIR Influent/Effluent concentration
measurements, 16 wafer dep. steps
“CDA Fire Mode”
SiH₄ and NH₃ flows under plasma

Chamber Clean
“CDA Fire Mode”

NF₃, Carrier flows

FTIR Influent/Effluent concentration
measurements
16 wafer dep. steps
“O₂ Fire Mode”
SiH₄, NH₃, N₂O flows

Total Effluent Flow Determination
MFC Metered Flows of SF₆ tracer gas at three
distinct flow setting per both O₂ and CDA fire
modes for dilution factor determination

FTIR Influent/Effluent concentration measurements
Chamber Clean
“O₂ Fire Mode”
NF₃, Carrier flows
Timeline for TPU Testing (Day 2)

MFC NF₃ Metered Flows
1500 sccm, 1250 sccm, 1000 sccm,
Plasma Off, for Influent Flow Determinations via FTIR

FTIR Influent/Effluent concentration measurements
Chamber Clean
“CDA Fire Mode”
NF3, Carrier flows

Total Effluent Flow Determination
MFC Metered Flows of SF6 tracer gas at three distinct flow setting per both O2 and CDA fire modes for dilution factor determination

FTIR Influent/Effluent concentration measurements
24 wafer dep. steps
“CDA Fire Mode”
SiH4, NH3 flows
# Average Influent/Effluent Flows and DFs

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
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<tbody>
<tr>
<td>Encompass Avg. Influent Flow</td>
<td>43.0 slm</td>
</tr>
<tr>
<td>TPU Avg. Influent Flow</td>
<td>44.5 slm</td>
</tr>
<tr>
<td>Encompass Avg. Effluent Flow, O₂ Fire</td>
<td>145 slm</td>
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<tr>
<td>Encompass Avg. Effluent Flow, CDA Fire</td>
<td>410 slm</td>
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<tr>
<td>TPU Avg. Effluent Flow, CDA Fire</td>
<td>419 slm</td>
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<tr>
<td>Encompass O₂ Fire DF</td>
<td>3.4</td>
</tr>
<tr>
<td>Encompass CDA Fire DF</td>
<td>9.5</td>
</tr>
<tr>
<td>TPU CDA Fire DF</td>
<td>9.4</td>
</tr>
</tbody>
</table>
Chamber Clean Step Results
Chamber Clean Testing Objectives

• What is the effective DRE for NF3?

• Is there appreciable destruction of NF3 in “CDA fire” mode?

  Certain fabs do not have available O2 supplies plumbed throughout the support level

  To claim abatement, MRR requires fabs to test their abatement units

• Are there differences in levels of NOx generated between the abatement units?
TPU NF₃ DRE in "CDA Fire"

Concentration NF₃ Out (PPM)

Timestamp

NF₃ in

NF₃ out

NF₃ DRE

NF₃ DRE (%)

Ratio of NF₃ in to NF₃ out over time.
Encompass NF$_3$ DRE in "O$_2$ Fire"
Encompass NF₃ DRE in "CDA Fire"

<table>
<thead>
<tr>
<th>Concentration (PPM)</th>
<th>Timestamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>NF₃in</td>
<td>15:30</td>
</tr>
<tr>
<td>NF₃out</td>
<td>15:33</td>
</tr>
<tr>
<td>NF₃DRE</td>
<td>15:36</td>
</tr>
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</table>
NF3 DRE Results

- Both Encompass operating in “O2 fire” mode and TPU in “CDA fire” mode achieved average DREs of about 99%.

  Extensive maintenance of the TPU was performed one day prior to testing including the combustor liner

  Previous testing by TI on other TPUs at another TI facility indicates that DRE is greatly affected by combustor liner plugging

- The average DRE for the Encompass in “CDA fire” mode was ~80%

- EPA Subpart I default DRE for NF3 is 88% from Table I-16
<table>
<thead>
<tr>
<th>Data Point</th>
<th>TPU Chamber Clean with &quot;O₂ Fire&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration NF₃ in (PPM)</td>
<td>0</td>
</tr>
<tr>
<td>Concentration NF₃ out (PPM)</td>
<td>0</td>
</tr>
<tr>
<td>Concentration N₂O out (PPM)</td>
<td>0</td>
</tr>
<tr>
<td>Concentration NO out (PPM)</td>
<td>0</td>
</tr>
<tr>
<td>Concentration NO₂ out (PPM)</td>
<td>0</td>
</tr>
</tbody>
</table>
Encompass NF3 Chamber Clean with "CDA Fire"
Encompass NF₃ Chamber Clean with "O₂ Fire"

Data Point

Concentration (PPM)

NF3in  NF3out  N2Oout  NOout  NO2out

Concentration
0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000 3200 3400 3600 3800 4000 4200 4400 4600 4800 5000 5200 5400 5600 5800 6000 6200 6400 6600 6800 7000 7200 7400 7600 7800 8000 8200 8400 8600 8800 9000 9200 9400 9600 9800 10000 10200 10400 10600 10800 11000 11200 11400 11600 11800 12000 12200 12400 12600 12800 13000 13200 13400 13600 13800 14000 14200 14400 14600 14800 15000 15200 15400 15600 15800 16000 16200 16400 16600 16800 17000 17200 17400 17600 17800 18000 18200 18400 18600 18800 19000 19200 19400 19600 19800 20000 20200 20400 20600 20800 21000 21200 21400 21600 21800 22000 22200 22400 22600 22800 23000 23200 23400 23600 23800 24000 24200 24400 24600 24800 25000

Concentration (PPM)
0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000 3200 3400 3600 3800 4000 4200 4400 4600 4800 5000 5200 5400 5600 5800 6000 6200 6400 6600 6800 7000 7200 7400 7600 7800 8000 8200 8400 8600 8800 9000 9200 9400 9600 9800 10000 10200 10400 10600 10800 11000 11200 11400 11600 11800 12000 12200 12400 12600 12800 13000 13200 13400 13600 13800 14000 14200 14400 14600 14800 15000 15200 15400 15600 15800 16000 16200 16400 16600 16800 17000 17200 17400 17600 17800 18000 18200 18400 18600 18800 19000 19200 19400 19600 19800 20000 20200 20400 20600 20800 21000 21200 21400 21600 21800 22000 22200 22400 22600 22800 23000 23200 23400 23600 23800 24000 24200 24400 24600 24800 25000

Data Point
Chamber Clean NO\textsubscript{x} Results

– The Encompass abatement unit running in “CDA fire” mode was very comparable to the TPU also in “CDA fire” mode

<table>
<thead>
<tr>
<th></th>
<th>Avg. NO (ppmv)</th>
<th>Avg. NO\textsubscript{2} (ppmv)</th>
<th>Avg. N\textsubscript{2}O (ppmv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encompass @ CDA Fire</td>
<td>645</td>
<td>169</td>
<td>152</td>
</tr>
<tr>
<td>TPU (CDA Fire)</td>
<td>787</td>
<td>163</td>
<td>236</td>
</tr>
</tbody>
</table>

• The two also have similar dilution factors

– The NOx concentration was markedly higher for the Encompass unit running in “O2 fire” mode
  • This is expected as higher temperatures will favor NO2 production
  • Interestingly, due to the lower total flow rate, the mass flow of NOx is actually less than the CDA fire modes
Mass Flow Rate of NOx

- Encompass O2 Fire
- Encompass CDA Fire
- TPU CDA Fire
Process Step Results
Process Step Testing Objectives

– What is the NH3 Removal Efficiency?

– Does the Encompass wet-burn-wet first stage remove the NH3 effectively and what are the differences in NOx production?
TPU Silicon Nitride Deposition Process with "CDA Fire"

Concentration Axis for NH₃ (PPM)

Data Point

NH₃out, NOout, NO₂out, N₂Oout, NH₃in
Encompass Silicon Nitride Deposition Process with "CDA Fire"

- NH3out
- NOout
- NO2out
- NH3in
Encompass CDA Versus TPU CDA NO\textsubscript{x} Out (Process Emissions)

Concentration (PPM)

Data Point

Enc CDA NO\textsubscript{out}
Enc CDA NO\textsubscript{2out}
TPU NO\textsubscript{out}
TPU NO\textsubscript{2out}
TPU N\textsubscript{2}O\textsubscript{out}
Process Step NO<sub>x</sub> Results

– Again, the Encompass abatement unit running in “CDA fire” mode was very comparable to the TPU also in “CDA fire” mode. The inlet concentrations of NH3 were pretty much identical.

<table>
<thead>
<tr>
<th></th>
<th>Avg. NO (ppmv)</th>
<th>Avg. NO₂ (ppmv)</th>
<th>Avg. N₂O (ppmv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encompass @ CDA Fire</td>
<td>34</td>
<td>8</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>TPU (CDA Fire)</td>
<td>212</td>
<td>31</td>
<td>251</td>
</tr>
</tbody>
</table>

– Appears that the first stage wet scrubber which allows removal of excess NH3 prior to the burn chamber, makes a significant difference in NOₓ and N₂O production. It is believed that excess NH can react with NO to produce N₂O.

\[
\text{NH} + \text{NO} \leftrightarrow \text{N}_2\text{O} + \text{H}
\]
Encompass Silicon Nitride Deposition Process with Undercoat and "O₂ Fire"
Process Step NO$_x$ Results (cont.)

– The Encompass running in “O2 fire” mode data seems to back up the efficacy of the first stage wet-scrubber as the N2O levels drop below detect after the pre-coat step.

– The N2O destruction efficiency of the Encompass in “O2 fire” mode also averaged ~99% although we do see increases in NOx production in the effluent as expected.

– It is also evident that the N2O/NOx levels did not fluctuate with NH3 input as seen in the TPU.
Miscellaneous Discussion
Utility and Maintenance

- Utilities forecasted for the Encompass were comparable to that of the existing Edwards TPU.

- Final cost analysis showed an increase of about 20% from forecasted costs, mainly due to water usage. However the costs of operation of the Encompass unit was still comparable to the TPU.

- The Encompass unit, once the testing was done, ran for ~13 months without maintenance needed. Repairs were needed after the unit developed a water leak. This ability to run without maintenance reduces the cost of operation of the Encompass significantly versus the TPU. Estimates show overall a difference of ~60% savings.

- Although particulates were not quantified, it was noticed that the Encompass effluent seemed to have a higher concentration of aerosol particulates than the TPU. It is theorized that the particulates may have been trapped by the ceramic liner used by the TPU. This is partially evident in the Encompass’ ability to run continuously without need for maintenance.
NOx and DRE Discussion

– It is important to take into account that NOx production is a complex issue and that the burners in both the Encompass and TPU unit were not tuned to minimize NOx prior to testing.

– In developing the Mandatory Reporting Rule Subpart I, EPA concluded that maintenance performed on an abatement unit could affect the DRE for greenhouse gases. Lowering the frequency of maintenance can give greater confidence that a unit is achieving the require DREs. Also, internal testing at TI has shown that TPU DRE degrades over time as chamber liner plugs up during normal processing.

– Also, as buildup in the combustion chamber is minimal (due to the Encompass Wetted Wall technology), maintenance is not expected to have any effect on DRE.
Future Evaluation Considerations

– Next step could potentially be to measure DREs again to track possible degradation over time of NF3

– Results from the wet-burn-wet technology seems promising in removing unwanted chemistries from reaching the combustion chamber. TI plans to evaluate a unit for tungsten oxide deposition