Process Tool Exhaust Management Improvements

Benefits of an integrated approach to sub-fab equipment

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Presentation content:

1. New processes and new challenges for process exhausts and POU abatement systems
2. Flammable gases in process exhausts
3. Mixed flammable gases and oxidants in process exhausts
4. Other hazardous gases in process exhausts
5. Control of condensation and blockage in process exhausts
6. Conclusions
New Processes Bring Additional Risks

New processes for HVM:
- New device structures need new materials
  - III-Vs, Co, Al₂O₃, metal carbide films.....
- New manufacturing processes bring additional risk
  - Epi, EUV...
  - Low temperature film growth
- High deposition rate for CVD
  - Increase process gas flow rate
- High etching rate
  - Increase process gas flow rate

Introduce additional risk:
- New hazardous process materials
  - Si₂H₆, AsH₃, TMA, CCTBA....
- High flow rate of hazardous gas:
  - Pyrophoric gas (Si₂H₆, TMA....)
  - Flammable gas (H₂....)
  - Toxic gas (AsH₃,...)
  - Corrosive gas (ClF₃, F₂, HBr, Br₂...)
- Condensation of liquids and solids in process exhaust pipes
  - Exhaust blockage
    - NH₄Cl, AlCl₃....
  - Reactive materials and by-products
    - Polysiloxanes, Br₂, TEOS....
Increased Risk to Fab and Staff

Risk to fab and equipment

- Leak of flammable or pyrophoric gas from exhaust pipes
- Air leak into forelines or exhaust pipes containing flammable gas
- Corrosion of pipework and gas leaks into the sub-fab

Risk to staff

- Fire hazard
- Toxic gas leak
- Hazardous material in exhaust pipes
Risk to Production – Exhaust Blockage

Condensed by-products block exhaust pipes

AlCl₃
• Metal etch

NH₄Cl
• LPCVD nitride

Exhaust pipe alarm pressure limit exceeded due to blockage

Atmospheric pressure

Exhaust alarm pressure (below atmosphere)

Extract duct pressure

Metal carbide CVD
• Unknown composition

Process Tool Exhaust Management Improvements
Control of Flammable Gases in Process Exhausts

- Flammable gas dilution for safety
- Impact on POU abatement TCOO
- An alternative method with reduced dilution
Flammable Gas Control by Dilution

Flammability Triangle

Air leak

Ignition source:
- POU abatement
- Dry pump

Process gas:
- H₂
- SiH₄
- Si₂H₆
- ...etc.

Safety control:
× Remove fuel
  • Cannot remove!
× Remove ignition source
  • Cannot remove!
✓ Control fuel < LFL

Add dilution gas

Extra cost
More utilities
High Dilution – Impact on POU Abatement

**Increased flammable gas flow**

<table>
<thead>
<tr>
<th>Gas</th>
<th>Max flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiH₄</td>
<td>3.5 slm</td>
</tr>
<tr>
<td>N₂O</td>
<td>56 slm</td>
</tr>
<tr>
<td>NH₃</td>
<td>45 slm</td>
</tr>
<tr>
<td>H₂</td>
<td>25 slm</td>
</tr>
<tr>
<td>NF₃</td>
<td>15 slm</td>
</tr>
<tr>
<td>4MS</td>
<td>5 slm</td>
</tr>
</tbody>
</table>

**CVD process chamber - New high-flow process**

- **Dilution of flammable gases below LFL**
  - Exhaust dilution > 600 slm

**Dry pump purge**
- 50 - 100 slm purge

**Total gas flow in POU abatement**
- ~ 700 - 900 slm

**Impact on POU abatement:**
- High total flow in POU abatement
- Extra POU abatement capacity required
- Reduced DRE due to high dilution
- Increased CAPEX
- Increased utilities consumption
- Increased footprint requirement
Flammable gas dilution strategy:

- **Dilute fuels below LFL**:
  - Increases total flow rate
  - Needs higher abatement capacity
  - Increases energy requirement
  - Total utilities consumption
  - Sub-fab footprint requirement
  - Increased abatement TCOO

- **Alternative flammable gas safety strategy**
  - Reduces total gas flow
  - Reduces abatement capacity requirement

- **Intelligent dilution control**
  - Apply dilution only when needed
  - Enables energy-efficient abatement of GHGs, PFCs, $F_2$, $ClF_3$

- **Process recipe-driven abatement operation**
  - “Normal” abatement modes for flammable gas (silane, TEOS)
  - “Energetic” abatement modes for GHGs, PFCs, $F_2$, $ClF_3
**Safety control:**

- Remove fuel
  - *Cannot remove!*
- Remove ignition source
  - *Cannot remove!*

**Control LOC**

- Eliminate air leaks
- Double containment of exhaust pipe joints
- Monitor O-seal condition

**Reduce dilution flow**

**Flammability Triangle**

**Process gas:**
- H₂
- SiH₄
- Si₂H₆
- ...etc.

**Ignition source:**
- POU abatement
- Dry pump

**LOC control keeps operating point out of flammable zone**
Monitored Joint Concept

Key features:
- Double-contained process gas seal
- In-situ leak-checking after maintenance
  - Non-invasive test
  - Reduces MTTR
- Real-time O-seal condition monitoring
  - Continuous monitoring of O-seal condition
  - Early warning of seal damage
  - Reduces unscheduled down-time

Key benefits:
- Reduces the risk of hazardous gas leak out of the exhaust
- Reduces the risk of air leak into exhaust
- Allows exhaust pipe to run at pressure above atmosphere without increased risk
- Increases MTBC
### Impact of Reduced Dilution on Abatement TCOO

<table>
<thead>
<tr>
<th>Exhaust pipe safety strategy</th>
<th>POU abatement capacity</th>
<th>POU abatement unit requirement</th>
<th>Relative utilities consumption per chamber</th>
<th>Relative abatement TCOO per chamber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dilute below 80% LFL</td>
<td>~ 400 slm</td>
<td>2 x POU abatement units per process module</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Dilute below 80% LFL</td>
<td>~ 700 slm</td>
<td>1 x POU abatement unit per process module</td>
<td>~ 76%</td>
<td>~ 56%</td>
</tr>
<tr>
<td>Control LOC (reduced dilution)</td>
<td>~ 400 slm</td>
<td>1 x POU abatement unit per two process modules</td>
<td>~ 28%</td>
<td>~ 25%</td>
</tr>
<tr>
<td>Control LOC (Reduced dilution)</td>
<td>~ 700 slm</td>
<td>1 x POU abatement unit per three process modules</td>
<td>~ 25%</td>
<td>~ 19%</td>
</tr>
</tbody>
</table>

- Example based on high flow W-CVD process including SiH₄, H₂
Control of Mixed Flammable Gases and Oxidants in Process Exhausts

- Standard dilution control for safety
- Impact on POU abatement TCOO
- An alternative method with reduced dilution
Processes Containing Fuels and Oxidants

**Process gas:**
- H₂
- SiH₄
- TEOS
- TMA
- ...etc.

**Ignition source:**
- POU abatement
- Dry pump

**Safety options:**
- Remove fuel
  - Cannot remove!
- Remove ignition source
  - Cannot remove!
- Remove oxidant
  - Cannot remove!

✓ Control N₂ dilution flow
   - N₂ flow safety interlock

**Air leak**

Flammability Triangle

- Flammable zone
- LOC
- Inert
- Oxidant
- Fuel

Dilution keeps the operating point out of flammable zone
Integration of Monitored Joint into a System

1. System Controller
   - Pressure inputs
   - \( N_2 \) flow inputs
   - Temperature inputs
   - Process tool inputs
   - Permissive signals
   - Alarms
   - Warnings
   - Data

2. Exhaust pipe with monitored joints
   - Prevent inward air leaks
   - Prevent outward toxic gas leak
   - Detect leaks and degraded seals
   - Locate leaking joint

3. Flame arrester system
   - Control / monitor total nitrogen flow
   - Latch burning flammable mixtures caused by upstream air leaks
   - Detect burning flammable mixtures

“Safe to process”
Process tool, CMS

LOC control in exhaust pipe
Dry pump

Dilution control and monitoring, inlet combustion monitoring

POU abatement system
Control of Other Hazardous Gases

- Integrated system enclosures
- Monitored Joint reduces leak risk
- High pressure limit extend MTBC
Integrated Systems Reduce Gas Leak Impact

Process gas leak in standalone equipment
- O-seal damage by corrosive process gas
- Thermal degradation of O-seal (brittle)
- Change in O-seal flexibility
- Mis-assembled O-seal
  ▶ Leak of hazardous gas into sub-fab
  ▶ Risk to staff

Integrated vacuum and abatement system
- Leaking gas extracted from enclosure
- Reduced risk to staff
Monitored Joint Concept Extends MTBC

Monitored Joint ensures safe operation:

- Double-contained process gas seal
- Real-time O-seal condition monitoring
  - Continuous monitoring of O-seal status
  - Early warning of seal damage

- Reduces the risk of hazardous gas leak out of the exhaust
- Allows exhaust pipe to run at high pressure without increased risk
- Extends MTBC of the exhaust pipe
Control of Condensation and Blockage in Process Exhaust Pipes

• Efficient pipe heating avoids or delays blockage
• Reduces risk to service staff
• Extends MTBC and improves uptime
Benefits of Exhaust Pipe Heating

Cold exhaust pipes lead to:
- Corrosion by condensed liquid
- Exhaust blockages
- Process interruption and downtime
- Build-up of hazardous materials
- Risk to service staff

Exhaust pipe heating provides:
- Reduced solids deposition
- Reduced condensation of corrosive liquids
- Extended MTBC / increased uptime
- Reduced risk to service staff
- Reduced maintenance time
Integrated Modular Pipe Heating Concept

Efficient thermal insulation
- High insulation efficiency
- Eliminates need for heaters on elbows
- Cut-to-shape insulation for straight pipe sections
- Modules for special pipe section (flanges, tees, elbows)

Modular pipe heaters in standard sizes
- Mix-and-match modules to fit pipe sections
- Heaters are not required for elbows
- Heater mat options for bypass valves

Integrated modular heating systems have some specific advantages:
- Modular flexible design improves turn-around time (supplier delay)
- Custom case-by-case design is not needed
- Separate heaters and insulation reduces service replacement costs
- Supplier of integrated systems has global experience of processes
- Easy to install and reconfigure
Conclusions
Conclusions

- New materials and processes will increase risks in the sub-fab
  - Impact of flammable / pyrophoric gas leak
  - Toxic / corrosive gas leak
  - Hazardous materials in exhaust pipes
  - Exhaust pipe blockage

- High flammable gas flow rates increases dilution gas cost significantly
  - N2 dilution cost
  - POU abatement utilities cost
  - CAPEX / OPEX / footprint increase

- Monitored Joint allows safe LOC control of flammable gases
  - Eliminates air leaks into exhaust pipes
  - Enables TCOO reduction (less N2, smaller POU abatement, less utilities consumption)

- Monitored Joint reduces exhaust pipe leak risk
  - Double-containment of O-seals in exhaust pipe joints
  - Continuous real-time monitoring of O-seal condition in exhaust pipe joints
  - Allows extended MTBC

- Modular exhaust pipe Temperature Management System reduces blockage issues
  - Eliminates risk to maintenance staff and fixes short MTBC issues
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