Supplying China: Combining local partnerships with global expertise by electronic material providers

Dr. Anish Tolia, Vice President of Global Marketing, Linde Electronics
March 2018
Established **wafer fabs**

1988 – 2015

Relative Wafer Capacity

- Domestic
- Foreign
New wafer fabs
2015-2022
Linde Electronics mainland footprint

- Bulk gas customer site
- Linde ASU site
- ESG plant
- ESG warehouse
- Linde Engineering centers
Why are gases important to semiconductors?
Bulk tanks for liquid argon, carbon dioxide, nitrogen, and oxygen

Where gases are used in the fab

Gas distribution system within the fab

On-site nitrogen

Bulk ESGs plus helium and hydrogen

Gas management system

On-site nitrogen

On-line chemical analysis

Gas purification system

Gas management system

Electronic specialty gases (ESGs) and chemical supply

Bulk tanks for liquid argon, carbon dioxide, nitrogen, and oxygen
Material and gases in global electronics manufacturing

Relative semiconductor spend $B

- Capex: 67
- R&D: 55
- Materials: 44

Electronic gas market $5B

- 60% ESGs
- 40% Bulk

Bulk gases

- Nitrogen
- Oxygen
- Argon
- Hydrogen
- Helium
- Carbon dioxide

Electronic special gas market $3000M

- Top 10 ESGs
  - NF₃
  - WF₆
  - NH₃
  - SiH₄
  - C₄F₆
  - Laser (Ne, Ar, Xe, F₂)
  - PH₃
  - N₂O
  - HCl
  - Si₂H₆

Capex
R&D
Materials

Semi
Display
LED
Solar

2016
2021
Examples of key processes that use ESGs

**Deposition**

- **Silicon Cl2H2 + NH3**
- **Si3N4**
- **Si**

Nitrogen gases: NH3, N2O
Silicon gases: SiH4, Si2H6, TCS, HCDS, TMS
Oxygen: O2
Tungsten hexafluoride: WF6
Germane: GeH4

Plasma / heat

**Lithography**

- **Deep UV laser**
- **Mask**
- **Lens**
- **Wafer**
- **SiON**
- **Si**

Laser gases: 95+% Ne, with Ar, Kr, and F2
Carbon dioxide: CO2
Hydrogen: H2

**Etching**

- **HBr + Cl2 + O2**
- **SiON**
- **Si**

Fluorocarbons: CxHyFz CF4, C2F6, C3F8, C4F8, C5F8, C4F6, CHF3, CH2F2, CH3F, C2HF5
Sulfur hexafluoride: SF6
Halides: HCl, Cl2, HF, F2, HBr, ClF3, XeF2
Oxygen: O2

Plasma / heat
Examples of key processes that use ESGs

**Doping**
- **Hydrides:** $\text{AsH}_3$, $\text{BF}_3$, $\text{B}_2\text{H}_6$, $\text{PH}_3$, $\text{GeH}_4$, $\text{Ge}_2\text{H}_6$
- **Oxygen:** $\text{O}_2$
- **Hydrogen:** $\text{H}_2$
- **Argon:** $\text{Ar}$
- **Nitrogen trifluoride:** $\text{NF}_3$
- **Other fluoride gases:** $\text{CF}_4$, $\text{C}_2\text{F}_6$, $\text{C}_4\text{F}_8$, $\text{ClF}_3$, $\text{SF}_6$
- **Chloride gases:** $\text{HCl}$, $\text{Cl}_2$
- **Fluorine:** $\text{F}_2$

**Annealing**
- **Original Si surface**
- **Oxide**
- **Si substrate**
- **Plasma / heat**

**Chamber Cleaning**
- **Plasma deposition**
- **Wafer**
- **Contaminated chamber**
- **Deposited film on sidewalls**
- **Chamber ready for next process**
- **Plasma cleaning**
Gas supply model

**On-site**
- Gas production and purification plant
- Pipeline
- On-site supply

**Bulk**
- Transport of liquefied gas

**Cylinder**
- ESG filling sites
China quality challenges
30 Years of mainland China semiconductor industry
Capacity growth and technology advancement

Cumulative MSI/year in China
MSI = millions of square inches of silicon

<table>
<thead>
<tr>
<th>Year</th>
<th>Capacity</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988</td>
<td>Domestic Only</td>
<td>small fabs for domestic/military purposes</td>
</tr>
<tr>
<td>1993</td>
<td>Domestic Only</td>
<td>many generations behind leading-edge</td>
</tr>
<tr>
<td>1998</td>
<td>Domestic Only</td>
<td>larger but isolated fabs</td>
</tr>
<tr>
<td>2003</td>
<td>Domestic + Foreign</td>
<td>foreign leading-edge + domestic-foreign JVs</td>
</tr>
<tr>
<td>2008</td>
<td>Domestic + Foreign</td>
<td>several generations behind leading-edge</td>
</tr>
<tr>
<td>2013</td>
<td>Domestic + Foreign</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>Big Fund Era</td>
<td>mega fabs and clusters of investment</td>
</tr>
<tr>
<td>2023</td>
<td>Big Fund Era</td>
<td>sustained government support for domestic leading-edge technology</td>
</tr>
<tr>
<td>2025</td>
<td>Big Fund Era</td>
<td></td>
</tr>
</tbody>
</table>
China semiconductor industry may be young...
But customers have same requirements
Between the variability of the raw material source...

Liaoning Fluorspar: HF, NF₃, SF₆, CF₄, etc.

Guangxi Tungsten: WF₆, WCl₅

Yunnan Germanium: GeH₄, Ge₂H₆
…and the precision of manufacturing
Material suppliers like Linde are the quality gatekeepers

<table>
<thead>
<tr>
<th>Source</th>
<th>Quality</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="source_image1.jpg" alt="Source Image" /></td>
<td><img src="quality_image1.jpg" alt="Quality Image" /></td>
<td><img src="use_image1.jpg" alt="Use Image" /></td>
</tr>
<tr>
<td><img src="source_image2.jpg" alt="Source Image" /></td>
<td><img src="quality_image2.jpg" alt="Quality Image" /></td>
<td><img src="use_image2.jpg" alt="Use Image" /></td>
</tr>
<tr>
<td><img src="source_image3.jpg" alt="Source Image" /></td>
<td><img src="quality_image3.jpg" alt="Quality Image" /></td>
<td><img src="use_image3.jpg" alt="Use Image" /></td>
</tr>
</tbody>
</table>
Managing supply chain determines quality

Measure at each step, prevent defects, continuous improvement

Raw materials

Receiving  Prep  Purification  Blending  Fill  QA/QC/Lab  Delivery

Final product quality

Traditional quality focus

Measurement systems analysis (MSA), Statistical process/Quality control (SPC/SQC)
Quality: Customers are driving tighter requirements

Customers
Expect Linde to meet purity specifications and control limits

Are even more concerned about unknown and uncontrolled impurities

Example
Specification: 50 ppm
Control limit: 20 ppm
Mean: 8 ppm
For bulk products, our customers see quality analysis in real time
Quality: local and consistent
Copy-exact procedures to produce consistent results

Suzhou Electronics Facility

Taichung Electronics Facility
Delivering quality requires control across the full supply chain.

Material providers like Linde are the quality gatekeepers.
China supply chain challenges
Importing electronic materials into China takes 10 – 50 days.
China raw material processor locations

- Shanghai port
- Anhui
- Jiangxi
- Jiangsu
- Zhejiang
- Sichuan
- Hebei
- Henan
- Shandong
- Tianjin
- Shanghai port
- Zhejiang
- Jiangxi
- Hubei
- Anhui
- Shandong
- Henan
- Hebei
- Sichuan

Distances:
- 500 km
- 1000 km
- 1500 km
- 2000 km
- 2500 km
Major supply disruptions can change how we do business

Tianjin Port Explosion: 2015
Major supply disruptions can happen for positive occasions

Beijing Olympics: 2008
Long-term Success for Materials Suppliers
Long-term success is integrating global expertise and stabilizing local capabilities and partnerships.

Start with global expertise

- Know-how
- Production
- Logistics
- Quality
- Safety
Long-term success is integrating global expertise and stabilizing local capabilities and partnerships

Start with global expertise
- Know-how
- Production
- Logistics
- Quality
- Safety

Invest in domestic capability
- R&D
- Production
- Distribution
- People
Long-term success is integrating global expertise and stabilizing local capabilities and partnerships

Start with global expertise
- Know-how
- Production
- Logistics
- Quality
- Safety

Invest in domestic capability
- R&D
- Production
- Distribution
- People

Partner with local raw materials suppliers
- Implement quality standards
- Secure Supply Chain