Manufacturing Equipment Innovations
Enabling 3D Architecture

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Strategic Partner of Choice for Today’s and Tomorrow’s Memory Technologies

Lam Research

- Plasma Processing
- Wet Processing
- Atomic-Layer Processing
- Mechatronics
- Software
- Services

Enabling 3D Architecture

- CPU Registers
- L1, L2, L3 Cache (SRAM, e-DRAM)
- Main Memory (DRAM)
- Storage Class Memory (SCM)
- Solid State Memory (SSD, Flash Drive)
- Virtual Memory (HDD)
Today’s and Tomorrow’s Scaling Is Enabled by 3D Architecture

The Vertical Reality

2D → 3D NAND

Planar → FinFET

Chip → Stacked Chip

Aspect Ratio ~9:1

The Burj Khalifa, tallest structure in the world

Aspect Ratio >40:1

Channel hole etched for 90+ layer 3D NAND

And simultaneously etch a trillion holes per wafer

Each hole is a diameter of ~x10^-3 of a human hair

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Deposition and Etch Processes Define 3D NAND Memory Array

- **Bitline:** Metal fill
  - SABRE® copper plating
- **Contact:** Metal fill
  - ALTUS® CVD/ALD deposition
- **Stair:** Staircase etch
  - Kiyo® conductor etch
- **Stack:** Alternating film deposition
- **Slit:** High aspect ratio etch
- **Channel:** High aspect ratio etch
- **Wordline:** Metal fill
  - ALTUS® CVD/ALD deposition

Lam is a leading equipment supplier in 3D NAND deposition and etch applications.
Breaking Fundamental Tradeoff with Equipment Innovation
Example: Memory Hole Etch - the Most Critical and Difficult Step in 3D NAND Manufacturing

High aspect ratio etch challenges due to transport limitation

- Mask consumed by ions at constant rate
- Neutrals shadowed and stick, can fail to reach bottom >40:1
- Ions weaken from induced voltages, 50% of ions may not reach bottom >50:1

Increasing engineering difficulty for high aspect ratio etches

- Equipment innovation required to break the fundamental tradeoff (AR, profile, mask selectivity)

Flex™ Channel Hole Etch
Atomic-scale process control is required in addition to micron-scale etched depths

Etched profile control precision: Angstroms
Etch depth capability: Microns
### New Class of Materials and New Manufacturing Challenges

<table>
<thead>
<tr>
<th>Memory Type</th>
<th>Electrode</th>
<th>Magnetic</th>
<th>Dielectric</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRAM</td>
<td>Ru, Ta, TiN</td>
<td>CoFe, NiFe, CoFeB, PtMn, IrMn, Ru</td>
<td>Al₂O₃, MgO, NiO</td>
</tr>
<tr>
<td>RRAM/CBRAM</td>
<td>W/Ag/Cu/Co/Mo/TaSN</td>
<td>(Ag-Ge-S/Cu-Ge-S)</td>
<td>Perovskite (CaTiO₃), PrCAMnO₃, transition metal Ox</td>
</tr>
<tr>
<td>FeRAM</td>
<td>Pt/Ir</td>
<td></td>
<td>PZT (PbZr1-xTixO₃): Y1 ((SrBiTa)O₃), doped HfO₂</td>
</tr>
<tr>
<td>Phase Change Memory (PCM)</td>
<td></td>
<td></td>
<td>Chalcogenide (Ge₂Sb₂Te, InSbTe)</td>
</tr>
<tr>
<td>3D NAND</td>
<td>Traditional materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DRAM</td>
<td>Traditional materials</td>
<td></td>
<td>ZrO/AlO/SrTiO</td>
</tr>
</tbody>
</table>

- **Increasing Etch Challenges**
- **Sensitive to chemistry and air exposure**
Innovative **Technology**
Trusted **Productivity**
Fast **Solutions**