Microelectromechanical Systems (MEMs)
Unit Processes for MEMs
Etching

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4-4-2008 mem_etch.ppt
OUTLINE

Basics
- Concentration, Molarity, Normality
- Selectivity, Anisotropy

Subtractive Processes
- Wet Etching
- Plasma Etching
- Endpoint Detection
- CMP

References
WET ETCH BASICS

Concentration: Often expressed as a weight percentage. That is the ratio of the weight of solute in a given weight solution. For example a solution containing 5 gms of solute in 95 grams of solvent is a 5 % solution.

Molarity: concentration expressed as moles of solute in 1 liter of solution. A solution containing one mole of solute in 1 liter of solution is termed a molar (1M) solution. A mole is the molecular weight in grams. Example: 10 gms of sulfuric acid in 500 ml of solution. H2SO4 has molecular weight of 1x2+32+16x4=98 so 10gms/98gm/M = 0.102M and 500ml is 1/2 liter, so this solution is 0.204 Molar
WET ETCH BASICS

Normality: concentration expressed as equivalents of solute in 1 liter of solution. One equivalent of a substance is the weight (1) which (as an acid) contains 1 gram atom of replaceable hydrogen; or (2) which (as a base) reacts with a gram atom of hydrogen; or (3) which (as a salt) is produced in a reaction involving 1 gram atom of hydrogen. Example 36.5 g of HCl contains 1 g atom of replaceable hydrogen and is an equivalent. 40 g of NaOH will react with 36.5 g of HCL which contains 1 g atom of hydrogen thus 40 g of NaOH is an equivalent. 98 grams of H2SO4 contains two gram atoms of hydrogen so 98/2 = 49 is one equivalent.

How many gams of sulfuric acid are contained in 3 liters of 0.5N solution? (answer: 74.5g)
**ISOTROPIC AND ANISOTROPIC ETCHING**

Isotropic Etching - etches at equal rate in all directions

Anisotropic Etching - etches faster vertically than horizontally

Wet Chemical Etching - is isotropic (except in crystalline materials)

Plasma Etching (Dry Etch or Reactive Ion Etching, RIE) - is either isotropic or anisotropic depending on ion energy and chemistry of etch.
**Degree of Anisotropy**

\[ A = \frac{z-x}{z} \]

- **Isotropic Etch**  
  \[ A = 0 \]
  - Substrate
  - Resist

- **Anisotropic Etch**  
  \[ A = 1 \]
  - Substrate
  - Resist

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**MEMs Unit Processes - Etching**

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ANISOTROPIC ETCH, HIGH ASPECT RATIO

Silicon Accelerometer

Courtesy of MCNC
**SELECTIVITY**

- **Rf** = etch rate for nitride film
- **Rpr** = etch rate for photoresist
- **Rox** = etch rate for pad oxide

We want **Rf** high and **Rpr**, **Rox** low

**Selectivity of film to Photoresist** = \( \frac{Rf}{Rpr} \)

**Selectivity of film to pad oxide** = \( \frac{Rf}{Rox} \)
We want $R_s$ high and $R_m, R_i$ low.

Selectivity of sacrificial oxide to Poly = $R_s/R_m$

Selectivity of sacrificial oxide to Nitride = $R_s/R_i$
DI WATER

City Water In
Mixed Bed Filter
Water Softener
Charcoal Filter
Heat Exchanger
Reverse Osmosis Filters (6 Mohm)
Storage Tank
Recirculation Pumps
Resin Bed Filters (Rho = 18 Mohm)
Ultraviolet Light Anti Bacteria System
Final 0.2 um Particulate Filters
Special Piping

DI Water Plant at RIT
RINSE TANKS

Cascade Rinser

1st Rinse

2nd Rinse

Dump Rinser

Spin Rinse Dry (SRD)

DI In

Drain

DI In

Drain

DI In

Drain

DI In

Drain
WET ETCHING OF SILICON DIOXIDE

HF with or without the addition of ammonium flouride (NH₄F). The addition of ammonium flouride creates a buffered HF solution (BHF) also called buffered oxide etch (BOE). The addition of NH₄F to HF controls the pH value and replenishes the depletion of the fluoride ions, thus maintaining stable etch rate.

\[
\text{SiO}_2 + 6\text{HF} = \text{H}_2\text{SiF}_6 + 2\text{H}_2\text{O}
\]

Types of silicon dioxide etchants:
- 49% HF - fast removal of oxide, poor photoresist adhesion
- BHF - medium removal of oxide, with photoresist mask
- Dilute HF - removal of native oxide, cleans, surface treatments
- HF/HCl or HF/Glycerin mixtures – special applications
7:1 NH₄F/HF gives about 1000 Å/min etch rate at room T

7 Parts 40% NH₄F and 1 part 48% HF
## ETCH RATES FOR VARIOUS TYPES OF SiO2

<table>
<thead>
<tr>
<th>Type</th>
<th>BOE (7:1)</th>
<th>Etch Rate (Å/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thermal SiO2</strong></td>
<td>1:1 HF:HCl</td>
<td>1,000 Å/min *</td>
</tr>
<tr>
<td></td>
<td>49% HF</td>
<td>23,000 Å/min **</td>
</tr>
<tr>
<td></td>
<td>KOH @ 72 °C</td>
<td>18,000 Å/min #</td>
</tr>
<tr>
<td></td>
<td>KOH @ 90 °C</td>
<td>900 Å/min *</td>
</tr>
<tr>
<td></td>
<td><strong>from Journal of MEMs, Dec.’96, Muller, et.al.</strong></td>
<td>2500 Å/min *</td>
</tr>
</tbody>
</table>

| **CVD SiO2 (LTO)**          | 1:1 HF:HCl                 | 3,300 Å/min #     |
|                             | 49% HF                     | 6,170 Å/min #     |

| **P doped SiO2**            | BOE (7:1)                  | 2000 Å/min        |
| (spin-on dopant)            | 1:1 HF:HCl                 | 25,000 Å/min      |
| (Photoresist adhesion problems) | 49% HF                   |                   |

| **Boron doped SiO2**        | BOE (7:1)                  | 200 Å/min*        |
| (spin-on dopant)            | 1:1 HF:HCl                 |                   |
|                             | 49% HF                     |                   |

| **Phosphosilicate Glass (PSG)** | BOE (7:1)                  | 10,000 Å/min #    |
|                                | 1:1 HF:HCl                 | 11,330 Å/min #    |
|                                | 49% HF                     | 28,000 Å/min      |

* RIT data, Dr. Fuller, et.al.
# from Madou Text
** from Journal of MEMs, Dec.’96, Muller, et.al.
### Summary of Etch Rates and Deposition Rates for RIT Processes

<table>
<thead>
<tr>
<th>Wet Etch Process Description</th>
<th>Date</th>
<th>Rate</th>
<th>Units</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.2:1 Buffered Oxide Etch (Transene) of Thermal Oxide, 300 °K</td>
<td>2/12/2008</td>
<td>1200</td>
<td>Å/min</td>
<td>EMCR650</td>
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<tr>
<td>5.2:1 BOE (Transene) Etch of PECVD TEOS Oxide, no anneal, 300 °K</td>
<td>2/12/2008</td>
<td>3840</td>
<td>Å/min</td>
<td>EMCR650</td>
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<tr>
<td>5.2:1 BOE (Transene) Etch of PECVD TEOS Oxide, anneal 1000 C - 60 min, 300 °K</td>
<td>1/22/2008</td>
<td>2029</td>
<td>Å/min</td>
<td>EMCR650</td>
</tr>
<tr>
<td>5.2:1 BOE (Transene) Etch of PECVD TEOS Oxide, anneal 1100 C - 6 hr, 300 °K</td>
<td>2/18/2008</td>
<td>1212</td>
<td>Å/min</td>
<td>EMCR731</td>
</tr>
<tr>
<td>10:1 Buffered Oxide Etch of Thermal Oxide, 300 °K</td>
<td>10/15/2005</td>
<td>586</td>
<td>Å/min</td>
<td>Mike Aquilino</td>
</tr>
<tr>
<td>10:1 BOE Etch of PECVD TEOS Oxide, no anneal, 300 °K</td>
<td>10/15/2005</td>
<td>2062</td>
<td>Å/min</td>
<td>Mike Aquilino</td>
</tr>
<tr>
<td>10:1 BOE Etch of PECVD TEOS Oxide, anneal 1000 C - 60 min, 300 °K</td>
<td>10/15/2005</td>
<td>814</td>
<td>Å/min</td>
<td>Mike Aquilino</td>
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<tr>
<td>10:1 BOE Etch of PECVD TEOS Oxide, anneal 1100 C - 6 hr, 300 °K</td>
<td>10/15/2005</td>
<td>562</td>
<td>Å/min</td>
<td>Mike Aquilino</td>
</tr>
<tr>
<td>Pad Etch on Thermal Oxide, 300 °K</td>
<td>12/1/2004</td>
<td>629</td>
<td>Å/min</td>
<td>EMCR650</td>
</tr>
<tr>
<td>Pad Etch of PECVD TEOS Oxide, 300 °K</td>
<td>6/8/2006</td>
<td>1290</td>
<td>Å/min</td>
<td>Dale Ewbank</td>
</tr>
<tr>
<td>Hot Phosphoric Acid Etch of Thermal Oxide at 175 °C</td>
<td>10/15/2005</td>
<td>&lt;1</td>
<td>Å/min</td>
<td>Mike Aquilino</td>
</tr>
<tr>
<td>Hot Phosphoric Acid Etch of TEOS Oxide, no anneal, at 175 °C</td>
<td>10/15/2005</td>
<td>17</td>
<td>Å/min</td>
<td>Mike Aquilino</td>
</tr>
<tr>
<td>Hot Phosphoric Acid Etch of TEOS Oxide, 1000 C 60 min Anneal, at 175 °C</td>
<td>10/15/2005</td>
<td>3.3</td>
<td>Å/min</td>
<td>Mike Aquilino</td>
</tr>
<tr>
<td>Hot Phosphoric Acid Etch of TEOS Oxide, 1100 C 6 hr Anneal, at 175 °C</td>
<td>10/15/2005</td>
<td>3.8</td>
<td>Å/min</td>
<td>Mike Aquilino</td>
</tr>
<tr>
<td>Hot Phosphoric Acid Etch of Si3N4 at 175 °C</td>
<td>11/15/2004</td>
<td>82</td>
<td>Å/min</td>
<td>EMCR650</td>
</tr>
<tr>
<td>50:1 Water:HF(49%) on Thermal Oxide at room T</td>
<td>10/15/2005</td>
<td>187</td>
<td>Å/min</td>
<td>Mike Aquilino</td>
</tr>
<tr>
<td>50:1 Water:HF(49%) on PECVD TEOS Oxide, no anneal, at room T</td>
<td>10/15/2005</td>
<td>611</td>
<td>Å/min</td>
<td>Mike Aquilino</td>
</tr>
<tr>
<td>50:1 Water:HF(49%) on PECVD TEOS Oxide, anneal 1000 C -30 min, at room T</td>
<td>10/15/2005</td>
<td>115</td>
<td>Å/min</td>
<td>Mike Aquilino</td>
</tr>
<tr>
<td>50:1 Water:HF(49%) of PECVD TEOS Oxide, anneal 1100 C - 6 hr, 300 °K</td>
<td>10/15/2005</td>
<td>107</td>
<td>Å/min</td>
<td>Mike Aquilino</td>
</tr>
<tr>
<td>KOH 20 wt%, 85 °C, Etch of Si (crystalline)</td>
<td>2/4/2005</td>
<td>30 μm/hr</td>
<td>EMCR870</td>
<td></td>
</tr>
<tr>
<td>KOH etch rate of PECVD Nitride (Low σ)</td>
<td>2/4/2005</td>
<td>10 Å/min</td>
<td>EMCR870</td>
<td></td>
</tr>
</tbody>
</table>
BUFFERED OXIDE ETCH TANK
In multilevel metal processes it is often necessary to etch vias through an insulating interlevel dielectric. Also if chips are given a protective overcoat it is necessary to etch vias through the insulating overcoat to the bonding pads. When the underlying layer is aluminum and the insulating layer is glass the etchant needs to etch glass but not etch aluminum. Straight Buffered HF acid will etch Aluminum.

A mixture of 5 parts BOE and 3 parts Glycerin works well. Etch rate is unaffected by the Glycerin. Original work was published by J.J. Gajda at IBM System Products Division, East Fishkill Facility, Hopewell Junction, NY 12533
Silox Vapox III – TRANSENE CO. (www.Transene.com)

This etchant is designed to etch deposited oxides on silicon surfaces. These oxides are commonly grown in vapox silox or other LPCVD devices and differ radically from their thermally grown cousins in many important ways. One way is their etch rate another is their process utility. The deposited oxide is many times used as a passivation layer over a metallized silicon substrate. Silox Vapox Etchant III has been designed to optimize etching of a deposited oxide used as a passivation layer over an aluminum metallized silicon substrate. This etchant has been saturated with aluminum to minimize its attack on the metallized substrate.

Deposited Oxide (Vapox/Silox) Etch Rate: 4000 Å / minute @ 22 °C

This product contains:
- Ammonium Fluoride
- Glacial Acetic Acid
- Aluminum corrosion inhibitor
- Surfactant
- DI Water
WET ETCHING OF SILICON NITRIDE

Silicon Nitride -

- BOE (7:1) 20A/min,
- 1:1 HF:HCL 120A/min,
- 49% HF 140 A/min
- 165°C Phosphoric Acid 55A/min (BOE dip first to remove oxynitride layer), etches silicon dioxide at 10 Å/min and silicon

Hot phosphoric acid etch of nitride can not use photoresist as an etch mask. One can use a thin patterned oxide (or oxynitride) to act as the etch mask. Etch rate for silicon is even lower than the etch rate of oxide.
HOT PHOSPHORIC ACID ETCH OF Si3N4

The boiling point of phosphoric acid depends on the concentration of H₃PO₄ in water. So if you heat the solution until it boils you can find the corresponding concentration. If you operate at the boiling temperature (temperature is controlled without a closed loop control system) and the water boils off, the concentration increases making the boiling point hotter. Thus reflux condensers and drip systems replace the water to control the concentration and boiling temperature.
HOT PHOSPHORIC ACID NITRIDE ETCH BENCH

- Warm up Hot Phos pot to 175°
- Dip in BHF to remove oxynitride
- Use Teflon boat to place wafers in acid bath
  - 3500Å +/- 500 → 50 minutes
  - 1500Å +/- 500 → 25 minutes
  - Etch rate of ~80 Å/min
- Rinse for 5 min. in Cascade Rinse
- SRD wafers
WET ETCHING

Aluminum - “Aluminum Etchant Type A” from Transene Co., Inc. Route 1, Rowley MA, Tel (617)948-2501 and is a mixture of phosphoric acid, acetic acid and nitric acid. Al/1%Si leaves behind a silicon residue unless the aluminum etch is heated to 50C.
WET ETCHING

Poly - KOH

Nickel - Use “Aluminum Etch Type A” at 50C, rate ~2000A/min

Chromium - CR-9 Etch, Cyantek Corp., 3055 Osgood Court, Fremont, CA 94539-5652, (510)651-3341

Gold - Gold Etch, J.E.Halma Co., 91 Dell Glen Ave, Lodi, NJ 07644

Copper - Ferric Chloride or mix Etchant from 533 ml water, add 80 ml Na₂S₂O₃, Sodium Persulfate, (white powder, Oxidizer), prepare in glass pan, place pan on hot plate and heat to 50 C (plate Temp set at 100 C)
# ETCHING OF Poly and Nitride in BOE, HF 49%, HF:HCl

<table>
<thead>
<tr>
<th>Material</th>
<th>BOE (7:1)</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitride</td>
<td>1:1 HF:HCl, 49%HF</td>
<td>20 Å/min #</td>
</tr>
<tr>
<td>Nitride (Silicon Rich)</td>
<td>1:1 HF:HCl, 49%HF</td>
<td>5 Å/min</td>
</tr>
<tr>
<td>Polysilicon</td>
<td>1:1 HF:HCl, 49%HF</td>
<td>0 Å/min</td>
</tr>
<tr>
<td>N+ Poly (Phosphorous)</td>
<td>1:1 HF:HCl, 49%HF</td>
<td>0 Å/min</td>
</tr>
</tbody>
</table>

* RIT data, Dr. Fuller, et.al.
# from Madou Text
** from Journal of MEMs, Dec.’96, Muller, et.al.
KOH etches silicon along the (111) crystal plane giving a 53° angle.
Si₃N₄ is the perfect masking material for KOH etch solution. The etch rate for Silicon Nitride appears to be zero.

When SiO₂ is used as a masking with a KOH solution both temperature and concentration should be chosen as low as possible. LTO is not the same as thermal oxide and can be attacked by KOH at a much higher rate. KOH etch rate is about 50 to 55 μm/min at 72 °C and KOH concentrations between 10 and 30 weight %. The Si/SiO etch ratio is 1000:1 for 10% KOH at 60 °C, at 30% it drops to 200:1. The relative etch rate of doped silicon to lightly doped silicon decreases for doping concentrations above 1E19 and at 1E20 the relative etch rate is 1/100 for 10% concentration. (on (100) wafer the angle is 50.6°)

C. Strandman, L. Rosengren, H. Elderstig, and Y Backlun uses Isopropyl Alcohol (IPA) added to the KOH mixture at 30 wt% before IPA was added. 250 ml of IPA per liter of KOH was added giving an excess of IPA on the surface of etchant during etching.
KOH ETCHING OF SILICON

KOH CONCENTRATION
- 10%
- 24%
- 42%
- 57%

BORON CONCENTRATION

Rochester Institute of Technology
Microelectronic Engineering
KOH ETCHING OF SILICON OXIDE
KOH ETCH APPARATUS

- Probe with glass cover
- Thermometer
- Teflon Cover
- Wafer Boat
- 20 wt% KOH + IPA
- Plastic Screw for Handle
- 70°C
- Wafers
- Holes
- Teflon Stirrer & Guide Plate
- Controller
- Hot Plate

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Microelectronic Engineering

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Dual 4 inch wafer holder with “O” ring seal to protect outer ½ “ edge of the wafer. Integral heater and temperature probe for feedback control system. Stainless steel metal parts do not etch in KOH.
**KOH ETCHING OF SINGLE CRYSTAL SILICON**

This is a summary of some of the results made in the RIT laboratory.

<table>
<thead>
<tr>
<th>Date</th>
<th>Etchant</th>
<th>Temp</th>
<th>Material</th>
<th>Etch Rate</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-23-96</td>
<td>10 wt% KOH no IPA</td>
<td>50°C</td>
<td>Si</td>
<td>16µm/hr</td>
<td>Fuller, did not see 51° angle</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Si3N4</td>
<td>0.0 Å/hr</td>
<td></td>
</tr>
<tr>
<td>5-23-96</td>
<td>20 wt% KOH no IPA</td>
<td>72°C</td>
<td>Si</td>
<td>50µm/hr</td>
<td>Stropko, set hotplate to 110°C to get 72°C, etched holes thru wafer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SiO2</td>
<td>900 Å/hr</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SiO2</td>
<td>2500 Å/hr</td>
<td></td>
</tr>
<tr>
<td>8-26-96</td>
<td>10 wt% KOH + IPA</td>
<td>70°C</td>
<td>Si</td>
<td>17.5µm/hr</td>
<td>Fuller/Babbitt, 10 um undercut</td>
</tr>
<tr>
<td>8-27-96</td>
<td>20 wt% KOH + IPA</td>
<td>75°C</td>
<td>Si</td>
<td>30µm/hr</td>
<td>Fuller/Babbitt,</td>
</tr>
</tbody>
</table>
## KOH ETCHING (continued)

<table>
<thead>
<tr>
<th>Date</th>
<th>Etchant</th>
<th>Temp</th>
<th>Material</th>
<th>Etch Rate</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-8-98</td>
<td>10% KOH</td>
<td>50 C</td>
<td>Si</td>
<td>25 μm/hr</td>
<td>Lundeen/Akpan</td>
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<tr>
<td></td>
<td>20%</td>
<td>75</td>
<td></td>
<td>62</td>
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<tr>
<td></td>
<td>10% + IPA</td>
<td>70</td>
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<td>12</td>
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<tr>
<td></td>
<td>20% + IPA</td>
<td>75</td>
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<td>10%</td>
<td>50</td>
<td>SiO2</td>
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<td>20%</td>
<td>75</td>
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<td>1680</td>
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<td></td>
<td>10% + IPA</td>
<td>50</td>
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<td>20% + IPA</td>
<td>75</td>
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<td>1500</td>
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<td>10%</td>
<td>50</td>
<td>LTO</td>
<td>4200 Å/min</td>
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<td>75</td>
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<td></td>
<td>20%</td>
<td>75</td>
<td></td>
<td>0</td>
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<tr>
<td>1-6-99</td>
<td>20% KOH</td>
<td>75</td>
<td>Si</td>
<td>60 μm/hr</td>
<td>Pushkar</td>
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<td></td>
<td>Si3N4</td>
<td>50 Å/hr</td>
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<tr>
<td>3-29-02</td>
<td>20% KOH</td>
<td>72</td>
<td>Si</td>
<td>53 Å/hr</td>
<td>EMCR890 Class</td>
</tr>
</tbody>
</table>
THIN DIAPHRAGM FORMATION

Heavily doped p-type silicon etches 100 times slower than lighter doped p-type silicon

\[ N(x,t) = N_o \text{erfc} \left[ x / \left( (4Dt)^{0.5} \right) \right] \]

Diaphragm Design: Select a 2 µm diaphragm thickness and a 500 µm by 500 µm size. Select boron diffusion at 1100 °C and calculate the diffusion time. What is the size of the etch opening if the wafer is 500 µm thick?
SEM PICTURES OF DIAPHRAGM ETCH

20% KOH Etch, @ 72 C, 10 Hrs.
PICTURES OF KOH ETCH PITS

SEM

Optical

20% KOH <100> Si Etch - 8 Hrs. @ 72C
**TYPES OF CASSETTS AND CARRIERS**

Black, Blue, Red wafer cassetts:
- Fluoroware PA182-60MB, PA72-40MB
- STAT-PRO© 100 (polypropylene)
- 6” wafers (SSI track, Canon stepper)
- 4” wafers (SVG track, GCA stepper)
- DO NOT USE IN WET CHEMISTRY

Teflon Chemical Process Wafer Cassett:
- Fluoroware A182-60MB
- PerFluoroAlkoxy (Teflon®) – heavy, medium
- High resistance to chemicals and temperature
- Can be used in wet chemistry processes
  (RCA clean, BOE etch, wet nitride etch, wet aluminum etch)
TYPES OF CASSETTS AND CARRIERS

Shipping Cassette:
- Empak PX9150-04
- Thin high purity polypropylene
- Available in 6” and 4” wafer sizes
- Not for use in processing
- DO NOT USE IN WET CHEMISTRY

Metal Cassette:
- Stainless steel
- Available for 6” and 4” wafers
- Use on Branson Asher only
- DO NOT USE IN WET CHEMISTRY
WET RESIST STRIP WITH BAKER PRS-1000

What steps will use wet strip?
Eventually all steps after Gate Oxide Growth

Why use wet strip?
Lower temperatures
No electric field from plasma
Gate oxide reliability increases

Harmful if swallowed or inhaled. Causes irritation to skin, eyes and respiratory tract.

Flashpoint 96C
Explosive vapors can be formed above this temperature (sealed container)
Processing temperature is 95°C
Etch rate calculated to be 760Å/minute
Process designed for 1000Å/minute
Inhibition layer could slow etch at start
10 minutes fully stripped most wafers
PHOTORESIST DEVELOPERS

CD-26     DI water
**RCA CLEAN WAFERS**

**APM**
- H₂O – 4500ml
- NH₄OH – 300ml
- H₂O₂ – 900ml
- 75 °C, 10 min.

**DI water rinse, 5 min.**

**HPM**
- H₂O – 4500ml
- HCL – 300ml
- H₂O₂ – 900ml
- 75 °C, 10 min.

**DI water rinse, 5 min.**

**What does RCA stand for?**
- **ANSWER**
- **PLAY**

**DI water rinse, 5 min.**
ETCHING THE DUAL-IN-LINE PLASTIC PACKAGE OFF OF PACKAGED CHIPS (DECAPSULATING)

Hot H$_2$SO$_4$ will etch the plastic package and not etch the metal wire bonds or other metal parts as long as no water is present. Straight H$_2$SO$_4$ heated to 100 C for 3 hours to remove all water. Allow to cool to 80C. This etch will remove a plastic package in 30 minutes. Immerse briefly in room temperature H$_2$SO$_4$ to cool the part, then rinse in DI water.
CA-40 Photomask Cleaning Solution Used as a soap with texwipe similar to cleaning dishes.
CLEANING SOLUTIONS
PLASMA ETCHING

Etch Chemistry
SF6
CF4
CHF3

Added Gases
O2
H2
He
C4F8

Added gases affect anisotropy, selectivity and etch rate
Lam 490 Etch Tool
Plasma Etch Nitride (~ 1500 Å/min)
SF6 flow = 200 sccm
Pressure = 260 mTorr
Power = 125 watts
Time = thickness/rate

Use end point detection capability
This system has filters at 520 nm and 470 nm. In any case the color of the plasma goes from pink/blue to white/blue once the nitride is removed.
RIE – Reactive Ion Etching

DRYTECH QUAD RIE
LAM 4900 Aluminum Etch Tool

| RF Top (W) | 0 | 0 | 0 | 0 | 0 | 0 |
| RF Bottom (W) | 0 | 350 | 275 | 275 | 0 |
| Gap (cm) | 3 | 3 | 3 | 3 | 5.3 |
| N2 | 25 | 25 | 40 | 50 | 50 |
| BCl3 | 100 | 100 | 50 | 50 | 0 |
| Cl2 | 10 | 10 | 60 | 45 | 0 |
| Ar | 0 | 0 | 0 | 0 | 0 |
| CFORM | 15 | 15 | 15 | 15 | 15 |
| Complete | Stabl | Time | Endpoint | Overetch | time |
| time (s) | 15 | 8 | 120 | 25% | 15 |
BASICS OF PLASMA ETCHING

CF4 is inert gas
add electron impact:

\[
\text{CF}_4 + e \rightarrow \text{CF}_3^+ + \text{F} + e \quad \text{(Dissociative Ionization)}
\]

\[
\text{CF}_4 + e \rightarrow \text{CF}_3 + \text{F} + e \quad \text{(impact dissociation)}
\]

To produce fluorine radicals. Then:

\[
\text{Si} + 4\text{F} \rightarrow \text{SiF}_4 \quad \text{(gas)}
\]
ADDED GASES AFFECT ETCH RATE

Relative Etch Rate

Etch Rate nm/min

- Pressure 25 mTorr
- Flow Rate 40 sccm

Mixtures

Percent O2

Percent H2 in CF4 + H2

- Resist
- SiO2
- Poly
ADDED GASES AFFECT SELECTIVITY

Hydrogen - reduces fluorine concentration by combination to form HF

Oxygen - Increases fluorine concentration by combining with carbon which would otherwise require fluorine or reacting with CF3 to liberate F

<table>
<thead>
<tr>
<th>Gas</th>
<th>C:F Ratio</th>
<th>SiO2:Si Selectivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>CF4</td>
<td>1:4</td>
<td>1:1</td>
</tr>
<tr>
<td>C2F6</td>
<td>1:3</td>
<td>3:1</td>
</tr>
<tr>
<td>C3F8</td>
<td>1:2.7</td>
<td>5:1</td>
</tr>
<tr>
<td>CHF3</td>
<td>1:2</td>
<td>10:1</td>
</tr>
</tbody>
</table>
ANISOTROPIC PLASMA ETCHING OF SILICON

SF6 plus CHF3, 50:50, 25 mTorr, 150 nm/min, 98% Anisotropy

**Fig. 1.** Silicon etch rate vs pressure for various SF$_6$ percentages in SF$_6$/CHF$_3$ mixture.

**Fig. 3.** Anisotropy vs pressure for various SF$_6$ percentages in the SF$_6$/CHF$_3$ mixture. For 100% SF$_6$, anisotropy is 0.6.

1.8 µm of poly etched in GEC tool with SF6 + CHF3 at 50 mTorr flow of 3 sccm and 3 sccm, power of 40 watts, time of 50 minutes. Results: etch rate for poly and photoresist is about the same, no undercutting, picture shows checkerboard with resist on the left and with no resist on the right. The top shows 5 µm lines. Poly etch rate of about 300 Å/min.

Plasma ignition made possible by closing throttle valve and letting the pressure rise to ~125 mTorr, then return valve to auto.
**SILICON ETCHING MECHANISM**

CF4 is Freon 14  
F/C ratio is 4  

\[ \text{CF}_4 + \text{e}^- \rightarrow \text{CF}_3 + \text{F} + \text{e}^- \]

F radicals adsorb on silicon surface; SiF4 desorbs  
CF3 radicals also adsorb  
CF3 + F \rightarrow C4 desorbs  

The presence of carbon on the surface reduces the amount of fluorine available to etch silicon. Carbon will leave the surface by combining with F reducing fluorine, carbon can remain on the surface forming C-F polymers which in turn inhibits etching. High F/C ratio favors etching. Adding O2 can increase etch rate and increases selectivity over oxide.
DRY ETCH SELECTIVITY AND ETCH RATE

- SUBSTRATE
- FILM
- RESIST

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Microelectronic Engineering
C3 and F radicals adsorb. C bonds with oxygen at the surface F bonds with Si. By-products are CO, CO2, COF2, SiF4. The addition of H2 removes F from the system by forming stable HF gas. Addition of H2 therefore decreases the effective F/C ratio and increases selectivity of SiO2 with respect to silicon. As H2 is increased, it begins to consume fluorine \( H + F = HF \) This slows the formation of SiF4 and slows the removal of Silicon. Polymerization will be promoted on all surfaces, which tends to inhibit etching. On horizontal surfaces however, ionic bombardment provides enough energy cause the carbon/hydrogen to combine with surface oxygen. Released CO and H2O expose the surface silicon which is removed by combining with released fluorine radicals. Silicon will not be etched because of the absence of oxygen at the surface.
POLYMER FORMATION

- H2 additions
- O2 additions
- CF4 plasma
- Increasing anisotropic
- Increasing SiO2:Si Selectivity
- Isotropic Etch
- Increasing Isotropic
- Increasing Pressure
- Ion Bombardment Energy

300 eV
Deep Reactive Ion Etch (DRIE) The Bosch process uses two chemistries, one to generate polymers and the other to etch silicon. The etch machine switches between the two every few seconds to ensure that the sidewalls are covered with polymer allowing fast, deep trench etching. (the substrate is on a chuck that is cooled by liquid nitrogen.

- 5µm spaces
- 200µm etch depth
- 40:1 aspect ratio
- 2µm/min Si etch rate
- >75:1 selectivity to photoresist
STS ETCH SYSTEM AT RIT

SF6 and C4F8
1 to 10 μm/min,
Oxide, Nitride or Photoresist masks.

Deep Reactive Ion Etch (DRIE)
STS ETCH SYSTEM AT RIT

Deep Reactive Ion Etch (DRIE)

13 sec etch in SF6 at 130 sccm plus O2 at 13 sccm
7 sec polymer deposition in C4F8 at 80 sccm

600 watts RF power
45 mTorr Pressure during etch
100 V wafer bias during etch

3 um/min etch rate
## PLASMA ETCHING OF VARIOUS MATERIALS

<table>
<thead>
<tr>
<th>Material</th>
<th>Kind of Gas Plasma</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>CF&lt;sub&gt;4&lt;/sub&gt;, CF&lt;sub&gt;4&lt;/sub&gt; + O&lt;sub&gt;2&lt;/sub&gt;, CCl&lt;sub&gt;2&lt;/sub&gt;F&lt;sub&gt;2&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>poly-Si</td>
<td>CF&lt;sub&gt;4&lt;/sub&gt;, CF&lt;sub&gt;4&lt;/sub&gt; + O&lt;sub&gt;2&lt;/sub&gt;, CF&lt;sub&gt;4&lt;/sub&gt; + N&lt;sub&gt;2&lt;/sub&gt;</td>
<td>doped or undoped</td>
</tr>
<tr>
<td>SiO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>CF&lt;sub&gt;4&lt;/sub&gt;, CF&lt;sub&gt;4&lt;/sub&gt; + O&lt;sub&gt;2&lt;/sub&gt;, HF*</td>
<td>*selective</td>
</tr>
<tr>
<td></td>
<td>CCl&lt;sub&gt;2&lt;/sub&gt;F&lt;sub&gt;2&lt;/sub&gt;, C&lt;sub&gt;3&lt;/sub&gt;F&lt;sub&gt;8&lt;/sub&gt;<strong>, C&lt;sub&gt;2&lt;/sub&gt;F&lt;sub&gt;6&lt;/sub&gt; + H&lt;sub&gt;2&lt;/sub&gt;</strong></td>
<td>**diode system</td>
</tr>
<tr>
<td>Si&lt;sub&gt;3&lt;/sub&gt;N&lt;sub&gt;4&lt;/sub&gt;</td>
<td>CF&lt;sub&gt;4&lt;/sub&gt;, CF&lt;sub&gt;4&lt;/sub&gt; + O&lt;sub&gt;2&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>Mo</td>
<td>CF&lt;sub&gt;4&lt;/sub&gt;, CF&lt;sub&gt;4&lt;/sub&gt; + O&lt;sub&gt;2&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>W</td>
<td>CF&lt;sub&gt;4&lt;/sub&gt;, CF&lt;sub&gt;4&lt;/sub&gt; + O&lt;sub&gt;2&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>Au</td>
<td>C&lt;sub&gt;2&lt;/sub&gt;Cl&lt;sub&gt;2&lt;/sub&gt;F&lt;sub&gt;4&lt;/sub&gt;</td>
<td></td>
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<tr>
<td>Pt</td>
<td>CF&lt;sub&gt;4&lt;/sub&gt; + O&lt;sub&gt;2&lt;/sub&gt;, C&lt;sub&gt;2&lt;/sub&gt;Cl&lt;sub&gt;2&lt;/sub&gt;F&lt;sub&gt;4&lt;/sub&gt; + O&lt;sub&gt;2&lt;/sub&gt;, C&lt;sub&gt;2&lt;/sub&gt;Cl&lt;sub&gt;3&lt;/sub&gt;F&lt;sub&gt;3&lt;/sub&gt; + O&lt;sub&gt;2&lt;/sub&gt;</td>
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<tr>
<td>Ti</td>
<td>CF&lt;sub&gt;4&lt;/sub&gt;</td>
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<tr>
<td>Ta</td>
<td>CF&lt;sub&gt;4&lt;/sub&gt;</td>
<td></td>
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<tr>
<td>Cr</td>
<td>Cl&lt;sub&gt;2&lt;/sub&gt;, CCl&lt;sub&gt;4&lt;/sub&gt;, CCl&lt;sub&gt;4&lt;/sub&gt; + Air</td>
<td>evaporate or sputter</td>
</tr>
<tr>
<td>Cr&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;</td>
<td>Cl&lt;sub&gt;2&lt;/sub&gt; + Ar, CCl&lt;sub&gt;4&lt;/sub&gt; + Ar</td>
<td>oxidation method</td>
</tr>
<tr>
<td>Al</td>
<td>CCl&lt;sub&gt;4&lt;/sub&gt;, CCl&lt;sub&gt;4&lt;/sub&gt; + Ar, BCl&lt;sub&gt;3&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>Al&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;</td>
<td>CCl&lt;sub&gt;4&lt;/sub&gt;, CCl&lt;sub&gt;4&lt;/sub&gt; + Ar, BCl&lt;sub&gt;3&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>GaAs</td>
<td>CCl&lt;sub&gt;2&lt;/sub&gt;F&lt;sub&gt;2&lt;/sub&gt;</td>
<td></td>
</tr>
</tbody>
</table>
PLASMA ETCHING OF VARIOUS MATERIALS

This is a summary of some of the results made in the RIT laboratory.

<table>
<thead>
<tr>
<th>Date</th>
<th>Etchant</th>
<th>Material</th>
<th>Etch Rate</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-8-98</td>
<td>SF6 (10sccm) +</td>
<td>LTO</td>
<td>800 Å/min</td>
<td>Josh Roberrge</td>
</tr>
<tr>
<td></td>
<td>CHF3 (15sccm)</td>
<td></td>
<td></td>
<td>Rick Anundson</td>
</tr>
<tr>
<td></td>
<td>50 watts, 270 mT</td>
<td>Thick Resist (no hard bake)</td>
<td>1875 Å/min.</td>
<td>Should Hardbake</td>
</tr>
<tr>
<td>3-1-98</td>
<td>SF6 (10sccm) +</td>
<td>LTO</td>
<td>1250 Å/min</td>
<td>Thresa Evans</td>
</tr>
<tr>
<td></td>
<td>CHF3 (15sccm)</td>
<td>Thermal SiO2</td>
<td>800 Å/min</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50 watts, 270 mT</td>
<td>Thick Resist</td>
<td>2100 Å/min</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Poly</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nitride</td>
<td>1648 Å/min</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>CHF3 only</td>
<td>105 Å/min</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SF6 off</td>
<td>Thick Resist</td>
<td>5 Å/min</td>
<td></td>
</tr>
</tbody>
</table>
END POINT DETECTION

Time
Plasma Brightness
Changes in Emission Spectrum
EMISSION SPECTRUM

The emission of light occurs when electrons, ions or molecules in a high energy state relax to a lower energy state. In a plasma, gas molecules are broken into fragments and excited to high energy states by the applied radio frequency power. These fragments recombine giving off photons equal in energy to the difference between the excited state and the relaxed state called an emission spectrum. In general plasmas are quite complex and the emission spectrum has many spikes and peaks at different wavelengths. Some of these spikes and peaks change as the chemistry of the plasma changes. For example in etching silicon nitride once the etching is complete the amount of nitrogen in the plasma goes to zero and peaks associated with nitrogen disappear. If the nitride is over oxide than once the nitride is gone the amount of oxygen in the plasma will increase and peaks associated with oxygen will appear. Usually several signals are watched at the same time to determine end point in plasma etching.
EMISSION SPECTROSCOPY

Light Emission (Many $\lambda$) → Prism or Grating → Light (Single $\lambda$) → Detector

Emission Intensity

Wavelength, $\lambda$
CALIBRATION

Your emission spectrometer can be calibrated by looking at well known emission spectra such as Hydrogen, which has peaks at 405, 438, 458, 486, and 656 nm.
Compare the emission spectra with no wafer to the spectra with a film being etched. Find a peak that represents a byproduct of the etch. Set the spectrometer on one or more of these characteristic peaks and monitor etch completion as these peaks change. For example in O2 plasma etch of photoresist there is a peak at 483.5 nm associated with CO which disappears at the end of the etch.

**O2 Plasma**
- **Wafer with Photoresist**
- **No Wafer in the System**

**CO peak at 483.5 nm**

**H2 peak at 656.5 nm**
Monitor the CO peak at 483.5 nm. During photoresist stripping there are large numbers of CO molecules. At end of Photoresist stripping the number of CO molecules is reduced.

O2, 30 sccm, 50 watts, 300 mTorr

BF2 heavy dose implant causes the surface to strip more slowly than bulk, thus initial CO emission is lower.
**POLY ETCH END POINT EXAMPLE**

- **End Point**
  - SF6 + O2
  - 704nm Line

- **Emission Spectra**
  - SF6 + O2 Plasma
  - No Silicon Wafer in System

- **Emission Spectra During Etching**
  - of Poly
  - in SF6 + O2 Plasma

---

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*Microelectronic Engineering*

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PLASMA ETCH TOOL

Lam 490 Etch Tool
Plasma Etch Nitride (~ 1500 Å/min)
SF6 flow = 200 sccm
Pressure= 260 mTorr
Power = 125 watts
Time=thickness/rate

Use end point detection capability
This system has filters at 520 nm and 470 nm. In any case the color of the plasma goes from pink/blue to white/blue once the nitride is removed.
LAM 490 END POINT

EPD Total Film Etch (1483A Nitride, 460A Pad oxide)

- Signal Intensity
- Time [sec]

85% Trigger
520nm

Nitride  Pad Oxide  Silicon

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LAM 490 PLASMA ETCH FOR 1500Å NITRIDE

- Follow LAM490 SMFL operations manual for start up
- Send FNIT1500.RCP
- Press ‘Recipe’ button on LAM to verify the Recipe
- Press ‘Parameters’ button and modify Endpoint 1 to match
- Proceed with Etch

Parameters
Endpoint 1
Press field select to change to endpoint setup screen and edit the following
Sampling A only [520nm ch 12]
Active during step 02
Delay 50 sec before normalizing
Normalize for 10 sec
Trigger @ 85% of normalized value

<table>
<thead>
<tr>
<th></th>
<th>Step 1</th>
<th>Step 2</th>
<th>Step3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>260 mT</td>
<td>260 mT</td>
<td>260 mT</td>
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<tr>
<td>RF Top</td>
<td>0</td>
<td>125</td>
<td>125</td>
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<tr>
<td>Gap</td>
<td>1.65</td>
<td>1.65</td>
<td>1.65</td>
</tr>
<tr>
<td>CF4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Helium</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SF6</td>
<td>200</td>
<td>200</td>
<td>200</td>
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<tr>
<td>Time &amp; Compl</td>
<td>Only</td>
<td>Endpoint</td>
<td>Overetch</td>
</tr>
<tr>
<td>Max</td>
<td>2 min</td>
<td>2 min 20s</td>
<td>40%</td>
</tr>
</tbody>
</table>

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**LAM 490 PLASMA ETCH FOR 6000Å POLY**

- Follow LAM490 SMFL operations manual for start up
- Send FACPOLY.RCP
- Press ‘Recipe’ button on LAM to verify the Recipe
- Press ‘Parameters’ button and **modify** Endpoint 1 to match
- Proceed with Etch

### Parameters

Endpoint 1
Press field select to change to endpoint setup screen and edit the following
- Sampling A only [520 nm ch 12]
- Active during step 02
- Delay 15 sec before normalizing
- Normalize for 10 sec
- Trigger @ 90% of normalized value

<table>
<thead>
<tr>
<th></th>
<th>Step 1</th>
<th>Step 2</th>
<th>Step 3</th>
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</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>325 mT</td>
<td>325 mT</td>
<td>325 mT</td>
</tr>
<tr>
<td>RF Top</td>
<td>0</td>
<td>140</td>
<td>140</td>
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<tr>
<td>Gap</td>
<td>1.65</td>
<td>1.65</td>
<td>1.65</td>
</tr>
<tr>
<td>CF4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Helium</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SF6</td>
<td>140</td>
<td>140</td>
<td>140</td>
</tr>
<tr>
<td>Time &amp; Compl</td>
<td>Only</td>
<td>Endpoint</td>
<td>Overetch</td>
</tr>
<tr>
<td>Max</td>
<td>2 min</td>
<td>1 min</td>
<td>15s 10%</td>
</tr>
</tbody>
</table>

Robert Saxer, Dan Brown, Dr. Fuller
## LAM 490 Etching of Parylene, Carbon Film (Diamond Like Film) and Photore sist Stripping

<table>
<thead>
<tr>
<th>Step 01</th>
<th>Step 02</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure = 225 mTorr</td>
<td>Pressure = 225 mTorr</td>
</tr>
<tr>
<td>Power = 0 watts</td>
<td>Power = 225 watts</td>
</tr>
<tr>
<td>Gap = 1.5 cm</td>
<td>Gap = 1.5 cm</td>
</tr>
<tr>
<td>O₂ Flow = 100 sccm</td>
<td>O₂ Flow = 100 sccm</td>
</tr>
<tr>
<td>He Flow = 50 sccm</td>
<td>He Flow = 50 sccm</td>
</tr>
<tr>
<td>Time = 60 sec</td>
<td>Time = thickness/rate</td>
</tr>
</tbody>
</table>

Chamber clean is same etch recipe with step 02 time of 10-20 min. using bare 150 mm silicon wafer

**Etch Rate (for Resist)** = 3500 Å/min  
**Etch Rate (for Parylene)** = 3000 Å/min  
**Etch Rate (for Carbon)** = 2500 Å/min
CMP EQUIPMENT SCHEMATIC

Conventional vs. Orbital


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SILICON WAFER CMP
**DAMASCENE PROCESS**

1. **Pattern Trenches in Oxide**
2. **Fill with Copper Metal**
3. **CMP Excess Metal Off**
REFERENCES


4. Scotten W. Jones and Steven T. Walsh, Wet Etching for Semiconductor Fabrication, Private Publication.


6. Transene Co. www.Transene.com
REFERENCES

HOMEWORK – MEMS ETCHING

1. Design a process to make a 1.5 µm diaphragm in single crystal silicon wafer of 500 µm thickness. Recommend photoresist opening size on the back of the wafer to give a 750 µm square diaphragm.
2. Look up the etch rate for poly, oxide and silicon nitride in HF/HCl.
3. If you are etching oxide off of silicon nitride in HF/HCl and you have to over etch to undercut some cantilever structures how far can you etch laterally before the underlying nitride is gone. Make reasonable assumptions.