Defect Reduction and Yield Enhancement, Part 1

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OUTLINE

Particulates
- Particle Definition
- Killer Defects
- Cost of a Killer Defect
- Yield Models
- Sources of Microcontamination
- Particle Counters and Scanners
- Particle Transport Mechanisms
- Defect Test Structures

Material Defects
- Wafer Defects
- Gettering
- Oxygen Precipitation
PARTICLE DEFINITION

Stable (Non-Volatile) Conglomeration of Molecules
Diameter ~2 nm to 2 mm
**KILLER DEFECTS**

**ANY PARTICULATE THAT CAUSES A DISRUPTION IN THE INTENDED MICROCIRCUIT PATTERN.**

Size is about the minimum feature size and needs to be in a critical spot on the wafer at a critical time in the manufacturing process.

**ANY CRYSTAL DEFECT THAT CAUSES A DISRUPTION IN THE INTENDED MICROCIRCUIT PATTERN.**

Defect needs to be near the surface (Top 5 to 30 micrometers)  
Defect needs to be in a critical device area.
KILLER DEFECTS (CONTINUED)

ANY CHEMICAL CONTAMINATE THAT CAUSES A DISRUPTION IN THE INTENDED ELECTRONIC DEVICE OPERATION.

Metals such as gold, copper, platinum etc causes decrease in lifetime of minority carriers causing devices such as memory and CCD's to fail (less than 10 parts per trillion)

Metals such as sodium and potassium causes shifts in threshold voltage of MOS FET's (less than one part per billion)

Metals such as boron, phosphorous, arsenic, aluminum, indium, antimony are semiconductor dopants (less than one part per million)
THE COST OF ONE KILLER DEFECT PER WAFER

assume 5000 6 inch wafer starts per week
assume 1 cm x 1cm size chip
assume $10 selling price

$$\text{AREA} = \pi R^2$$

$$(3.14)(7.5 \text{ cm})^2 = 176 \text{ cm}^2$$

$$\text{NUMBER OF DIE/WAFER} = \frac{\text{AREA}}{\text{DIE AREA}}$$

$$= 176 \text{ die}$$

$$\text{NUMBER OF DIE PER YEAR} =$$

$$= (50000 \text{ wfr/wk})(52 \text{ wk/yr})(176 \text{ die/wfr})$$

$$= 45,760,000 \text{ die/year}$$

$$\text{DOLLARS/YEAR} = \$457,600,000/\text{year}$$

$$\text{COST OF ONE ADDITIONAL KILLER DEFECT / WFR}$$

$$= \frac{\$457,600,000}{176} = \$2,600,000/\text{year}$$
IDENTIFY SOURCE OF CONTAMINATION

Root Cause Analysis by Blank Wafer
DRT - “O” Ring Contamination

Rochester Institute of Technology
Microelectronic Engineering
SEMATECH COST RESOURCE MODEL SENSITIVITY

% Cost Change per 1% Change in Variable

- Probe Yield
- Fab Yield
- Throughput
- Downtime %
- Tool Capital
- Consumables
- Materials
- Maintenance
- space
- Salaries
- Clean Room Layout
- Operators
YIELD MODELS

\[ \text{YIELD} = e^{-AD} \]

WHERE
- \( A \) is the \text{CHIP AREA} (cm\(^2\))
- \( D \) is the \text{DENSITY OF DEFECTS} (#/cm\(^2\))

EXAMPLE: \text{CHIP AREA} is 1 cm\(^2\) and \text{DEFECT DENSITY} is 1/cm\(^2\)

then \[ \text{YIELD} = e^{-1} = 37\% \]
MAXIMUM NUMBER OF PARTICLES PER CUBIC FOOT OF AIR

0.1 um 0.2um 0.3um 0.5um

<table>
<thead>
<tr>
<th>CLASS</th>
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<th>7.5</th>
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<td></td>
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<td>CLASS 1000</td>
<td>1000</td>
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CLEANROOM DESIGN

BALLROOM DESIGN
TUNNEL AND CHASE DESIGN
MINI-ENVIRONMENT

Ballroom Design
PARTICLES AND THEIR SOURCE

Iron oxide from welding process

Fly ash from coal burning power generation

Asbestos

Ref: William Hinds, “Aerosol Technology”
MINI ENVIRONMENT

SMIF Cassette Loading
Tools

Open Cassette Loading

SMIF Cassette
People can generate up to 2,000,000 particles per minute. By using white suits and other clean room protocols this number can be reduced to less than 10,000 particles per minute.
The skin we shed

- Sitting quietly: 100,000/min
- Walking 3kph: 5.0 million/min
- Walking 5kph: 7.5 million/min
- Walking 8kph: 10 million/min

Source: Dr. Ken Goldstein Cleanroom Consultants, and Mike Fitzpatrick, Lookwood Greene, Cleanrooms East 99
Finding a 1µm particle on an 8” wafer is equivalent to finding a penny in the city of Rochester, NY
PARTICLE COUNTS OVER A WORKDAY

Laser Particle Counter (LPC) 3A and 3B and Condensation Nucleation Counter (CNC) 4A all at the same location in the fab.
POSITIVE PRESSURE IN A CLEANROOM

24 HOUR TRACE OF PARTICLE COUNT AND CLEANROOM PRESSURE

Figure 8-7a. A 24-h particle concentration profile measured near the reticle cleaner.
Figure 9-7. Periodic bursts of particles larger than 10 nm in the vicinity of a photoresist spinner.

Source: Donovan et al., 1988
PARTICLES NEAR LPCVD LOAD STATION

Figure 9-8. Particle concentration from the loading area of a low pressure chemical vapor deposition furnace.

Source: Donovan et al., 1988
## MICRO CONTAMINATION IN IC MANUFACTURING

### RCA CLEAN AND WET ETCH
- **Particles in liquids**: 2
- **Particles on surface of baths**: 4
  - (Langmire film deposition)
- **Process design**: 8

### PLASMA ETCH
- **Particles formed by the process**: 10
- **Particles from the gas source**: 2

### DIFFUSION
- **Particles generated in diffusion furnace**: 4
  - Due to mechanical movement
- **Particles from the gas source**: 2
MICRO CONTAMINATION - EQUIPMENT & PROCESS

PHOTOLITHOGRAPHY
- drips
- airborne dust
- solids in the resist
- particles from dried developer
- particles from spinners

METALIZATION
- flakes from previous depositions

HANDELING
- marks and scratches
- edge marks from boats and positioning fixtures
- particles from storage boxes
FACILITIES PROBLEMS

- loss of positive pressure: 5
- dirty equipment: 8
- dirty areas: 8
- people: 8
- HEPA filter failure: 2
- air flow problems: 8
- procedures: 10

LPCVD

- flakes from previous depositions: 10
- particles formed by the process: 10
- particles from the gas source: 2

ION IMPLANT

- basically clean: 0
- mechanical movement: 2
REVIEW

TODAY REDUCTION IN PARTICULATE CONTAMINATION IS CENTERED AROUND IMPROVEMENTS IN EQUIPMENT AND PROCESSES.

THE CLEANROOM CAN SHOW PARTICLE BURSTS MANY ORDERS OF MAGNITUDE ABOVE THE NOMINAL BACKGROUND PARTICULATE LEVEL.

MINI-ENVIRONMENTS OFFER FURTHER IMPROVEMENTS IN CLEANROOM ENVIRONMENTS.
PARTICLE COUNTERS

- Scattered Light Counters Give Size and Count and Are Accurate down to 0.3 um
- Particle Size is related to scatter angle
- Condensation Nucleus Counter can be used for particles smaller than 0.3 um
  - particles are drawn through a saturated vapor (often alcohol) making the particles large enough to be counted
  - particle size is not easy to determine once nucleation is used
AIR BORN PARTICLE COUNTER

INPUT AIR SAMPLE

LASER

DETECTOR ARRAY AND COUNTER

PARTICLE SIZE IS RELATED TO SCATTER ANGLE

PUMP
(LPC) Laser Particle Counter counts air born particles <0.3, 0.5, 1.0 2, 5, >10 µm sizes. System also measures temperature, humidity and air flow.
METONE PARTICLE COUNTER
### EXAMPLE PARTICLE COUNT DATA

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Temp</th>
<th>Hmd</th>
<th>10µm</th>
<th>5µm</th>
<th>2µm</th>
<th>1µm</th>
<th>0.5µm</th>
<th>0.3µm</th>
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<td>1.18</td>
<td>66.4</td>
<td>37.4</td>
<td>1</td>
<td>1</td>
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<td>84</td>
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<td>348</td>
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<td>69</td>
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<td>467</td>
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<td>1-29-96</td>
<td>12.28</td>
<td>66.1</td>
<td>50.5</td>
<td>2</td>
<td>3</td>
<td>32</td>
<td>47</td>
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<td>45</td>
<td>122</td>
<td>717</td>
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</table>
SURFACE PARTICLE SCANNER

PARTICLE SIZE IS RELATED TO SCATTER ANGLE

DETECTOR ARRAY AND COUNTER

ROTATING MIRROR SCANNER

LASER

WAFER WITH PARTICULATES
TENCORE SURF SCAN

Gives total surface particle count and count in 4 bins <0.5, 0.5 to 2.0, 2.0-10, >10. Bin boundary can be selected. Edge exclusion eliminated count from near the edge of the wafer.
### EXAMPLE SURFACE PARTICLE COUNT DATA

**Before Cleaning (75 mm)**

<table>
<thead>
<tr>
<th>Size Range (µm)</th>
<th>Count</th>
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</thead>
<tbody>
<tr>
<td>0.2 - 0.5</td>
<td>104</td>
</tr>
<tr>
<td>0.5 - 2.0</td>
<td>562</td>
</tr>
<tr>
<td>2.0 - 10</td>
<td>19</td>
</tr>
<tr>
<td>&gt;10</td>
<td>2</td>
</tr>
</tbody>
</table>

**After Cleaning (75 mm)**

<table>
<thead>
<tr>
<th>Size Range (µm)</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 - 0.5</td>
<td>10</td>
</tr>
<tr>
<td>0.5 - 2.0</td>
<td>4</td>
</tr>
<tr>
<td>2.0 - 10</td>
<td>3</td>
</tr>
<tr>
<td>&gt;10</td>
<td>0</td>
</tr>
</tbody>
</table>
PARTICLE TRANSPORT MECHANISMS

RAINDROP MODEL (NOT ACCURATE)

\[ F = C \cdot V \]

- \( F \) = DEPOSITION FLUX (# / sec / unit area)
- \( C \) = PARTICLE CONCENTRATION (# / ft^3)
- \( V \) = AIR VELOCITY (ft / sec)

EXAMPLE: Class 100 clean room with air velocity of 100 ft/min

\[ F = \frac{(100)(100)}{60} (\frac{2.54}{12})^2 = 0.02 \text{ particles/cm}^2 \text{ / sec} \]

This is close but overestimates the number of particles because some do not adhere to the surface. The relationship can be useful if \( V \) is replaced by an effective velocity \( V_{eff} \) called the aerosol particle deposition velocity.
**PARTICLE DEPOSITION MODELS**

\[ V_{eff} = \text{Aerosol Particle Deposition Velocity (number of particles / time)} \]

\[ F = C \times V_{eff} \]

or \[ V_{eff} = \frac{F}{C} \]

Where we find \( F \) from monitor wafers using a surface particle counter and \( C \) is measured using an Airborne Particle Counter.

Example: After 8 hours in a class 100 clean room a 4 inch monitor wafer shows an increase in surface particle count from 50 to 550 particles.

\[ V_{eff} = \frac{(550-50)}{(8 \times 60 \times 60)\left(\pi \left(\frac{2}{12}\right)^2\right)} \text{particles/ft}^2\text{sec / 100 particles/ft}^3 \]

\[ = 0.12 \text{ ft/min} \quad \text{or} \quad 0.61 \text{ cm/sec} \]
### Veff VERSUS SIZE AND PRESSURE

**Increasing Air Velocity**

- **Aerosol Region**
  - 1um
  - 0.01um
- **Gravitational Region**
  - 100 f/m
  - 50
  - 25
  - 12

**PARTICLE SIZE**

- 0.01um
- 0.1um
- 1um
- 10um

**Veoff cm/sec**

- $10^0$
- $10^{-1}$
- $10^{-2}$
- $10^{-3}$
**ELECTRIC FIELD EFFECTS**

**Increasing Particle Charge**

- Neutral
- $Q$
- $10xQ$

**Surface at 100 V/cm**

<table>
<thead>
<tr>
<th>Particle Size</th>
<th>$V_{eff}$ (cm/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01um</td>
<td>$10^{-2}$</td>
</tr>
<tr>
<td>0.1um</td>
<td>$10^{0}$</td>
</tr>
<tr>
<td>1um</td>
<td>$10^{2}$</td>
</tr>
<tr>
<td>10um</td>
<td>$10^{4}$</td>
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</tbody>
</table>
TEMPERATURE EFFECTS

<table>
<thead>
<tr>
<th>Temperature</th>
<th>$V_{eff}$ (cm/sec)</th>
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</thead>
<tbody>
<tr>
<td>20°C</td>
<td>$10^{-4}$</td>
</tr>
<tr>
<td>80°C</td>
<td>$10^{-1}$</td>
</tr>
</tbody>
</table>

The graph shows a linear decrease in effective velocity ($V_{eff}$) with increasing temperature.
TIME TO SETTLE VERSUS PRESSURE

- Low pressure
- High pressure
- 0.1 um
- 1 um
- 10 um

TIME

10^0
10^2
10^4
10^6

PRESSURE

LOW

HIGH

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ELECTRICAL EFFECTS CAN INCREASE THE DEPOSITION VELOCITY BY 2-3 ORDERS OF MAGNITUDE, EVEN FOR LOW FIELDS OF 100 V/M.

HEATING THE WAFER CAN HELP PROTECT IT FROM PARTICULATES, 50 C CAN HELP BY ONE ORDER OF MAGNITUDE.

WAFFERS SHOULD BE FACE DOWN IN VACUUM SYSTEMS. WHERE GRAVITY IS THE IMPORTANT PARAMETER. (CAUTION: IN PLASMA SYSTEMS ELECTRIC FIELD IS MORE IMPORTANT THAN GRAVITY).

AEROSOL PARTICLE DEPOSITION RATE IS A FUNCTION OF PARTICLE SIZE.
STATIC CHARGE

Static Charge causes a surface to be positive or negatively charged. This surface will attract oppositely charged particles and neutral particles from the air.

Sources of Static Charge:

- Triboelectric or Friction Charging
- Charging through Induction
- Ion implant, SEMs or plasma processes

All air ionization systems work by flooding the atmosphere with positive and negative ions. When ionized air comes in contact with a charged surface, the charged surface attracts ions of the opposite polarity. As a result, the static electricity that has built up on products, equipment and surfaces is neutralized.

Ions are created by high electric fields (a combination of high voltages and sharp emitter tips). The voltage can be AC (60 Hz), DC, or Pulsed. In the case of AC the air near the tips must be moving fast enough to not recombine with oppositely charged ions generated 1/60 sec later from the same tip. In DC systems a continuous high voltage is applied generating equal numbers of + and - ions. Pulsed systems apply pulsed DC high voltages. Each pulse can be negative or positive and can have separately adjusted duty cycle. Pulsed systems allow more flexibility.
Pulsed DC systems use positive and negative emitter points that are turned on and off alternately to create clouds of positive and negative ions. Cycle timing and polarity can be adjusted to provide the required balance and level of static control needed in a specific environment.
A charged plate monitor is an instrument that has an isolated conductive plate (~ 4 inches square) that can be charged to 1000 volts and the time it takes to discharge to 10% (100 volts) is determined. In normal air at 60% humidity the decay may take 12 hours. An ionization system can reduce the decay time to less than one minute.
DEFECT TEST STRUCTURES

Via chain is sensitive to contact cut problems.

Comb Structure is sensitive to Shorts and less sensitive to opens if $W > S$
Serpentine Structure is sensitive to opens and less sensitive to shorts if \( S > W \)

\[
R = (\text{Rhos}) \times \frac{L}{W}
\]

- **No Defects**
  - \( R = R_1 \)

- **Short**
  - \( R \ll R_1 \)

- **Open**
  - \( R \gg R_1 \)
METAL AND DIFFUSION SERPENTINE

Line width = 15 µm
Line Space = 30 µm
L/W = 269
Area Covered by metal = 62050 µm²

Defect density ( in #/cm² ) = (# defective x 1612) / (# tested)

R = Rhos L/W
## DEFECT TEST DATA FROM 1994 AT RIT

<table>
<thead>
<tr>
<th>SERPENTINE</th>
<th>METAL</th>
<th>POLY</th>
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</thead>
<tbody>
<tr>
<td>LINE WIDTH (µm)</td>
<td>3 6 9</td>
<td>2 4 6</td>
</tr>
<tr>
<td>SPACE (µm)</td>
<td>9 18 27</td>
<td>4 12 18</td>
</tr>
<tr>
<td>AREA (µm²)</td>
<td>27117 23820 24147</td>
<td>31088 27920 23820</td>
</tr>
<tr>
<td>DEFECTS FOUND</td>
<td>34 2 1</td>
<td>ALL 32 2</td>
</tr>
<tr>
<td>DEVICES MEASURED</td>
<td>53 53 53</td>
<td>53 53 53</td>
</tr>
<tr>
<td>YIELD</td>
<td>36% 96% 98%</td>
<td>0% 40% 96%</td>
</tr>
<tr>
<td>DEFECTS/cm²</td>
<td>2366 158 78</td>
<td>INFINITE 2162 158</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>COMB</th>
<th>METAL</th>
<th>POLY</th>
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<td>6 12 18</td>
</tr>
<tr>
<td>SPACE (µm)</td>
<td>3 6 9</td>
<td>2 4 6</td>
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<td>AREA (µm²)</td>
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<tr>
<td>DEFECTS FOUND</td>
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<td>3 3 3</td>
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<tr>
<td>DEVICES MEASURED</td>
<td>53 53 53</td>
<td>53 53 53</td>
</tr>
<tr>
<td>YIELD</td>
<td>98% 100% 98%</td>
<td>94% 94% 94%</td>
</tr>
<tr>
<td>DEFECTS/cm²</td>
<td>70 0 83</td>
<td>216 207 219</td>
</tr>
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</table>
CRYSTAL DEFECTS

1. interstitial impurity
2. edge dislocation
3. self-interstitial
4. precipitate of substitutional atoms
5. small dislocation loop formed by agglomeration of self-interstitials
6. substitutional impurity, widening lattice
7. vacancy
8. dislocation loop formed by agglomeration of vacancies
9. substitutional impurity, compressing lattice
10. Schottky defect
11. interstitial arriving from surface
12. Frenkel defect
INFLUENCE OF CRYSTAL DEFECTS ON DEVICES

- Leakage Currents in PN Junctions
  - Precipitates, Dislocations
- Collector-Emitter Leakage in BJTs
  - Precipitates, Dislocations
- Minority Carrier Lifetime
  - Point Defects, Point-Defect Clusters
- Gate Oxide Quality, Oxide leakage, Oxide Breakdown Voltage
  - metallic contamination, defect density on surface, oxygen precipitates at the surface
- Threshold Voltage Control
  - surface state density
BASIC GETTERING PRINCIPALS


2. Remove Existing Crystal Defects by High Temperature Annealing or Creation of Oxygen Denuded Zones at the wafer surface, removing Oxygen precipitates near the surface.

3. Remove Point Defects by Gettering (capturing contaminates at locations away from device locations)

Yield Improvements Can Be Made
Cu, Ni, Au, Fe are highly mobile and diffuse long distances at moderate temperatures, find defects and are captured

Cu can diffuse 600 um in 1 min at 900 C
Fe can diffuse 100 um in 1 min at 1000 C

Low Temperature Processes introduce fewer impurities from the furnace.
HCl Cleaning of Furnace Tubes
Double Wall Furnace Tubes
Eliminate Metal Tweezers
Replace Stainless Steel with Silicon, Carbon and Aluminum Parts
EXTRINSIC GETTERING

HEAVY PHOSPHOROUS DIFFUSION OF THE BACKSIDE OF THE WAFER WILL CAUSE DEFECTS THAT CAN CAPTURE METAL CONTAMINATES

MECHANICAL DAMAGE TO BACKSIDE OF THE WAFER, ABRAISON, SANDBLASTING

LASER DAMAGE

ION IMPLANT DAMAGE

DEPOSITION OF POLYSILICON ON BACK OF WAFER
INTRINSIC GETTERING

STARTING WAFERS WITH 15-19 PPMA OXYGEN CONCENTRATION

1. DENUDED ZONE FORMATION - HIGH TEMPERATURE STEP TO REDUCE OXYGEN CONCENTRATION NEAR WAFER SURFACE

2. NUCLEATION OF SiO2 CLUSTERS - LOWER TEMPERATURE STEP

3. PRECIPITATE GROWTH AND GETTERING - HIGH TEMPERATURE STEP FOR GROWING SiO2 CLUSTERS AND FORMING DISLOCATION LOOPS, GETTERING SITES
15-19 ppm Oxygen Starting Wafers

- T1 = 1100 °C, t1 = 240 min., give 10-40 um Denuded Zones
- T2 = 600 °C, 4 to 64 hours, nucleate 50 A radius sites
- T3 = 1100 °C, 4 to 16 hours, Grow 1000 A radius sites

15-20 ppm Oxygen Starting Wafers

- T1 = 1100 °C, t1 = 240 min., give 10-40 um Denuded Zones
- T2 = 600 °C, 4 to 64 hours, nucleate 50 A radius sites
- T3 = 1100 °C, 4 to 16 hours, Grow 1000 A radius sites

Rochester Institute of Technology
Microelectronic Engineering
Contamination from high temperature furnace operation

Furnace tube used for p-type or n-type diffusion will dope bare wafers simply by transfer of dopant molecules from the furnace wall to the wafers.

In the case of Boron, B2O3, Boric Oxide, from spin on glass and glass transferred from solid sources

In the case of Phosphorus, P2O5, melts at 360°C and is a gas at high temperatures. This glass is a vapor at 900°C and can move from surface to surface and dope a bare silicon substrate.
REMEDIES FURNACE CONTAMINATION

Ceramic Liners
Chlorine
Procedures to Prevent Contamination
When solids are heated they will go to the liquid state (Hg is already liquid at room T) at the melting point. Solids will also go to the gas state at the correct combination of temperature and pressure. This is the vapor pressure and is often given as a function of temperature. As pressure is decreased the temperature at which solids will vaporize lowers and if this temperature is below the melting point then the material will sublimate (go to gas state without going through the liquid state). In our LPCVD systems and sputtering systems temperatures around 400 °C and pressures below 1x10^-5 Torr are common. At these temperatures and pressures many metals sublime and can be a source of contamination for the next users of the system. For example, Zinc is a component of brass, cadmium is used to plate steel screws, sulfur and selenium are used in stainless steel ver-#303. These materials all sublime at 400 °C and 1x10^-5 Torr and will contaminate the equipment as a result.
### MELTING POINT & VAPORIZATION PRESSURE DATA FOR VARIOUS MATERIALS

<table>
<thead>
<tr>
<th>Material</th>
<th>Melt Point</th>
<th>Vapor Pressure</th>
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<tbody>
<tr>
<td></td>
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<td>$10^{-8}$  $10^{-6}$ $10^{-4}$</td>
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<tr>
<td>Al</td>
<td>660</td>
<td>677    812  1010</td>
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<tr>
<td>Arsenic</td>
<td>814</td>
<td>107    152  210</td>
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<tr>
<td>Barium</td>
<td>725</td>
<td>545    627  735</td>
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<tr>
<td>Beryllium</td>
<td>1278</td>
<td>710    878  1000</td>
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<tr>
<td>Bismuth</td>
<td>271</td>
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<tr>
<td>Boron</td>
<td>2100</td>
<td>1278   1548 1797</td>
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<tr>
<td>Boron Nitride</td>
<td>2300</td>
<td>-      -     1300</td>
</tr>
<tr>
<td>Cadmium</td>
<td>321</td>
<td>64     120  180</td>
</tr>
<tr>
<td>CdS</td>
<td>1750</td>
<td>550</td>
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<tr>
<td>CdTe</td>
<td>1098</td>
<td>450</td>
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<tr>
<td>Chromium</td>
<td>1890</td>
<td>837    977  1177</td>
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<tr>
<td>Gallium</td>
<td>30</td>
<td>619    742  907</td>
</tr>
<tr>
<td>GaAs</td>
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<td>Ge</td>
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<td>677    812  1010</td>
</tr>
<tr>
<td>Gold</td>
<td>1062</td>
<td>807    947  1132</td>
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<tr>
<td>Hafnium Oxide</td>
<td>2812</td>
<td>-      -     2500</td>
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<tr>
<td>Iron Oxide</td>
<td>1425</td>
<td></td>
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<tr>
<td>Nickel</td>
<td>1453</td>
<td>927    987  1262</td>
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<tr>
<td>Platinum</td>
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<td>1292   1492 1747</td>
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<tr>
<td>Selenium</td>
<td>217</td>
<td>89     125  170</td>
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<tr>
<td>Silver</td>
<td>961</td>
<td>574    617  684</td>
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<tr>
<td>Tantalum</td>
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<td>1960   2240 2590</td>
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<td>Tungsten</td>
<td>3410</td>
<td>2117   2407 2757</td>
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<td>Zinc Oxide</td>
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<td></td>
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<tr>
<td>Zirconium</td>
<td>1852</td>
<td>1477   1702 1987</td>
</tr>
</tbody>
</table>
Via Failure

A slew of detailed process problems can lead to via failures.

Vias can pull away from the metal layer.

Stress management
Control stresses in Cu

Poor fill
Voids migrate to via bottom

Seed/M2 interface
Seed contamination

Undercut
Poor barrier coverage

Barrier/M1 interface
Poor clean = TaN + CxNy

SiN/Cu adhesion
Metal 1 relaxation at via
REFERENCES

4. VLSI Technology, Ch. 14 - “Yield and Reliability”, Sze.
11. Ion Systems, 1005 Parker Street, Berkeley A  94710, ionsys@ion.com.
1. Calculate the defect density for the following examples:
   (a) 256K DRAM with die size 0.4 cm by 0.4 cm and Yield of 75%
   (b) 1M DRAM with die size of 1.4 cm by 0.4 cm and Yield of 55%
   (c) 4 M DRAM with die size of 1.4 cm by 1.4 cm and Yield of 20%

2. What defect density will be needed to give a 85% Yield on 16M devices with area four times the 4 M DRAM in problem 1.
This homework refers to the following articles and abstracts:

Generate a set of two questions and answers that illustrate the main points of each article. (total of 10 questions with answers)