Clean Rooms
How Big of a Particle is Tolerable?

– Example: 0.5 µm CMOS technology
  • Lateral Features:
    – pattern size = 0.5 µm
    – pattern tolerance = 0.15 µm
    – level-level registration = 0.15 µm
  • Vertical Features:
    – gate oxide thickness = 10 nm
    – field oxide thickness = 20 nm
    – film thicknesses = 250-500 nm
    – junction depths = 50-150 nm
Filtration Media

• Fibers
  – “depth” filters
  – many randomly oriented intertangled strands laid into a mat
    • Fourdrinier process, usually submicron glass fibers
  – void volume is typically about 85 - 90 %

• Membranes
  – “surface” filters
  – homogeneous sheet material with holes punched into it
    – 1. cellulose nitrate; void volume is about 70 - 85 %
      • holes formed by solvent evaporation, irradiation, or stretching
    – 2. polycarbonate sheets; void volume is about 10 - 20 %
    – 3. PTFE sheets; biaxially stretched
    – 4. sintered silver particles
Clean Room Air Filters

- **High Efficiency Particulate Air (HEPA) Filters**
  - most common type of clean room air filter
  - high efficiency, low pressure drop, good loading characteristics
  - uses glass fibers in a paper-like medium
  - are rated by their particle retention:
    - A true HEPA-rated filter will retain 99.97% of incident particles of 0.3 μm or larger. (DEFINITION)
HEPA History

– developed during WWII atomic bomb research for containment of radioactive aerosols
– called “superimpingement” or “superinterception” filters; later referred to as “absolute” filters
– first prototype filters used esparto grass as the filter medium
– in 1950s glass fibers were introduced into the paper
– in 1960s specifications were standardized and called HEPA filters
– in 1970s asbestos was removed
– in 1960 the first laminar flow bench was invented at Sandia National Laboratory
– HEPAs have now been developed by the semiconductor industry to far outstrip their original specifications
HEPA Filter Types

<table>
<thead>
<tr>
<th>Type</th>
<th>Application</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>industrial, noncritical</td>
<td>&gt; 99.97 % @ 0.3 µm (MIL-STD-282)</td>
</tr>
<tr>
<td>B</td>
<td>nuclear containment</td>
<td>&gt; 99.97 % @ 0.3 µm (certified by DOE)</td>
</tr>
<tr>
<td>C</td>
<td>laminar flow</td>
<td>&gt; 99.97 % @ 0.3 µm (MIL-STD-282)</td>
</tr>
<tr>
<td>D</td>
<td>ultra-low penetration air (ULPA)</td>
<td>&gt; 99.9995 % @ 0.12 µm</td>
</tr>
<tr>
<td>E</td>
<td>toxic, nuclear, and biohazard</td>
<td>MIL-F-51477</td>
</tr>
<tr>
<td></td>
<td>containment</td>
<td>MIL-F-51068</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(classified performance)</td>
</tr>
</tbody>
</table>

Grade 1 = fire resistant
Grade 2 = semicombustible
HEPA / ULPA Characteristics

- Most submicron fabrication lines use Type-D ULPA filters as an improvement over traditional HEPAs for Class-1 and Class-10 environments.
- Usual size is 3 ft. x 6 ft. x 5.875 in. frame.
- When new, maximum pressure drop is 1 in of H₂O = 0.036 psi
- Each ft² of opening corresponds to about 50 ft² of paper area.
- Designed for 90 lfm air velocity, or 45.7 cm/sec.
- Designed for entraining 500 - 1000 grams of dust per 1000 cfm
- Are sealed into the ceiling using gel-sealed T-bars
- Typical lifespan is several years if air is properly prefiltered
HEPA Filter Construction

- Metal separator grids
- Pleated layers of fiber lay paper
- Pressboard frame
- Air flow direction
Physics of Fiber Filtration

conditions: 1.0 µm fiber radius; 0.1 packing density; 10 cm/s air velocity

overall efficiency

diffusion

inertial impact

interception

single fiber efficiency

particle diameter, microns
Advanced Air Filtration Methods

– Particles around the 0.1 \( \mu m \) size range are most difficult to filter.
– Reducing air velocity decreases the fractional penetration.
– New trend is to use electrostatic methods in series with HEPAs and ULPAs
  • Obtain a factor of 10 improvement from corona precharging
  • Obtain another factor of 10 improvement from corona precharging followed by collector electrification

Fractional Penetration of 0.1 \( \mu m \) Particles

<table>
<thead>
<tr>
<th>Filter Type</th>
<th>Air Velocity</th>
<th>Fractional Penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEPA @ 7 cm/s</td>
<td>10^{-3}</td>
<td></td>
</tr>
<tr>
<td>HEPA @ 3.5 cm/s</td>
<td>10^{-4}</td>
<td></td>
</tr>
<tr>
<td>ULPA @ 7 cm/s</td>
<td>10^{-4}</td>
<td></td>
</tr>
<tr>
<td>ULPA @ 3.5 cm/s</td>
<td>10^{-5}</td>
<td></td>
</tr>
<tr>
<td>ULPA @ 1.25 cm/s</td>
<td>10^{-6}</td>
<td></td>
</tr>
</tbody>
</table>
Clean Room Class Ratings

**FIGURE 1**
Air cleanliness according to U.S. Fed. Std. 209E.

**FIGURE 2**
Air cleanliness according to Japanese Std. B9920 rev.

from *ULSI Technology* by Chang and Sze
## Clean Room Class Ratings

<table>
<thead>
<tr>
<th>Class</th>
<th># 0.5 µm particles per ft³</th>
<th># 5.0 µm particles per ft³</th>
<th>air changes per hour</th>
<th>ceiling filter coverage (%)</th>
<th>air velocity (fpm)</th>
<th>max. vibration (µin/s)</th>
<th>temp. tolerance</th>
<th>RH tolerance</th>
<th>approx. capital cost per ft²</th>
</tr>
</thead>
<tbody>
<tr>
<td>office</td>
<td>100,000</td>
<td>100,000</td>
<td>12-18</td>
<td>18-30</td>
<td>10</td>
<td></td>
<td>±3.0°F</td>
<td>±5%</td>
<td>$10</td>
</tr>
<tr>
<td>100,000</td>
<td>100,000</td>
<td>650</td>
<td>12-18</td>
<td>18-30</td>
<td>10</td>
<td></td>
<td>±3.0°F</td>
<td>±5%</td>
<td>$50</td>
</tr>
<tr>
<td>10,000</td>
<td>10,000</td>
<td>65</td>
<td>40-60</td>
<td>30</td>
<td>10</td>
<td></td>
<td>±3.0°F</td>
<td>±5%</td>
<td>$200-250</td>
</tr>
<tr>
<td>1,000</td>
<td>1,000</td>
<td>6.5</td>
<td>40-60</td>
<td>30</td>
<td>10</td>
<td></td>
<td>±2.0°F</td>
<td>±5%</td>
<td>$350-400</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
<td>0.65</td>
<td>40-60</td>
<td>80-100</td>
<td>75-90</td>
<td>500</td>
<td>±1.0°F</td>
<td>±5%</td>
<td>~$1200</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>0.065</td>
<td>40-60</td>
<td>80-100</td>
<td>75-90</td>
<td>250</td>
<td>±0.5°F</td>
<td>±3%</td>
<td>~$3500</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0.0065</td>
<td>540-600</td>
<td>100</td>
<td>90-100</td>
<td>250</td>
<td>±0.3°F</td>
<td>±2%</td>
<td>~$10,000+</td>
</tr>
<tr>
<td>.5</td>
<td>.5</td>
<td>0.0033</td>
<td>540-600</td>
<td>100</td>
<td>100-110</td>
<td>125</td>
<td>±0.1°F</td>
<td>±1%</td>
<td>~$25,000+</td>
</tr>
</tbody>
</table>
Types of Cleanrooms - 1

FIGURE 7
Cleanroom with centrifugal fan units installed on top of process level.

from ULSI Technology by Chang and Sze
Types of Cleanrooms - 2

FIGURE 8
Cleanroom with axial fan units installed sideways connecting the air-supply plenum at the top and the air-return plenum at the bottom.

from ULSI Technology by Chang and Sze

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Types of Cleanrooms - 3

FIGURE 9
Cleanroom with filter fan units installed on the top of process area.

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Types of Cleanrooms - 4

from *ULSI Technology* by Chang and Sze

R. B. Darling / EE-527
Characteristics of Clean Rooms

– Air is recirculated through HEPA filters with about 20 % make up.
  • Vapors are entrained, so contamination potential is very high
  • Extensive gas detection and alarm systems are installed
– Temperature is controlled to 68 - 72 °F.
– Humidity is controlled to 40 - 46 % RH.
– Room is held at positive pressure
  • Typically 0.1 in of H$_2$O for Class 100, Class 1000, and Class 10,000
  • Typically 0.3 - 0.4 in of H$_2$O for Class 1 and Class 10
  • Positive pressure constantly blows dust OUT
  • (Biohazard rooms operate at negative pressure to keep bugs IN)
  • Doors open inward, so room pressure closes them shut
  • 0.1 in H$_2$O = 3.6 x 10$^{-3}$ psi = 0.52 lb/ft$^2$
  • This produces 9.1 lbs. force on a 7’ x 30” door
Laminar Flow Benches

- A HEPA filter used to provide local clean air conditions
  - Can usually drop the class rating by 2 decades within a local area
  - Example: Class 100 local environment within a Class 10,000 room
- Designed to minimize turbulence which creates dust and dirt collection pockets
- Vertical style used above free standing equipment and load zones
- Horizontal style used behind microscope and inspection benches
- Benches usually have built-in air diffusers, lights, and occasionally shutters to close off the workspace from the outside
Vertical and Horizontal Laminar Benches

- Blower
- HEPA
- Air Intakes
- C-frame stand
- Process Equipment
- C-frame cover
- Inspection Microscope
- Work Stands

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Gowning - Class 10,000

Putting On

- Shoe Covers
- Laboratory Coat
- Hair Net
- Safety Glasses
- Clean Room Gloves

Taking Off

R. B. Darling / EE-527
Gowning - Class 100

Shoe Covers
Hair Net
Gowning Gloves
Bunny Suit
Booties
Hood
Nose/Mouth Mask
Safety Glasses
Clean Room Gloves
Face Shield
Respirator

outside clean area
for handling wafers

Putting On

Taking Off

R. B. Darling / EE-527
Clean Room Dos and Don’ts

• Don’t:
  – touch your face or skin with gloves
  – touch building hardware, oily machinery, or wafer loading areas
  – lean on equipment
  – wear cosmetics, powders, or colognes
  – wear anything on fingers—remove all rings and bracelets
  – use paper, pencils or markers that leave dust or lint

• Do:
  – change gloves whenever they get dirty or torn
  – use a fresh pair of gloves whenever handling wafers
  – wipe down wafer handling areas with isopropanol
  – use clean room paper and dust-free ball point pens
Bringing Items In and Out

- Everything should be double bagged
  - Use zip-lock bags or aluminum foil or plastic wrap
- Once cleaned and sealed inside a clean room, items should not be opened unit inside another clean room
- Standard clean and degrease is required for all new items entering the clean room