

ECEn 452 – Semiconductor Devices Lab  
Week 2: “Intro to the Cleanroom and Metal Deposition”  
Background Reading

**What is a Clean Room?**

***BS 5295 Definition***

"Environmental cleanliness in enclosed spaces". "A Clean Room is a room with environmental control of particulate contamination, temperature and humidity, constructed and used in such a way as to minimize the introduction, generation and retention of particles inside the room."

**Why are they needed?**

To reduce contamination levels in the product or services performed.

***Contamination Control Technology***

Contamination control technology concerns itself with every single thing that happens within the Clean Room. How items are handled, cleaned and stored, what equipment is used and the method of its use. What materials are used in the process and what changes take place to that material, what are the contaminants, where do they come from and how can they be eliminated. Clean Room technology is the part of the contamination control that concerns itself with the design, facilities, air handling equipment, and construction techniques. As such it deals with the removal of particles from the air and the levels of air cleanliness that can be achieved.

**How are they classified?**

The determination of how clean an area is, depends on the classification that it has been designed to. The classification of air cleanliness in FED standard 209 is very simple as the class is directly related to the number of particles per cubic foot of air equal to or greater than 0.5  $\mu$ m (micron).

***209B Defines four classes of air cleanliness***

- 1. Class 100,000:*** Particle count not to exceed a total of 100,000 particles per cubic foot of a size 0.5 $\mu$ m (micron) and larger or 700 particles per cubic foot of a size 5.0 $\mu$ m (micron) and larger.
- 2. Class 10,000:*** Particle count not to exceed a total or 10,000 particles per cubic foot of a size 0.5 $\mu$ m (micron) and larger or 65 particles per cubic foot of a size 5.0 $\mu$ m (micron) and larger.
- 3. Class 1,000:*** Particle count not to exceed a total of 1000 particles per cubic foot of a size 0.5 $\mu$ m (micron) and larger or 10 particles per cubic foot of a size 5.0 $\mu$ m (micron) and larger.

**4. Class 100:** Particle count not to exceed a total of 100 particles per cubic foot of a size 0.5µm (micron) and larger.

Remember - The Clean Room class is generally achieved in the "at rest" state when there are no people in the room!

### **Where do particles come from?**

#### ***Clean Room Air***

The task of the Clean Room filter is to ventilate the atmosphere with microbial and particulate free air. They create a positive pressure, so that any air-borne contaminants present are from within the room.

- The source of micro-organisms is from people.
- The source of particulates are from people and processes.

#### ***Microbes***

Microbes are dispersed from skin cells, and a human body sheds the outermost layer of skin every 24 hours.

- 1 BILLION SKIN FLAKES EVERY 24 HOURS.

A skin flake is typically 33 microns - 44 microns. They break down to typically 20µm (micron) but 7-10% are less than 10µm (micron). The equivalent diameter of bacteria carrying particles is 12-14µm (micron). These settle by gravity at 0.37 meters per second.

- 12-14µm (micron) size particles will settle in wounds of hospital patients and aseptically filled containers in pharmaceutical applications by gravity.

#### ***Inert Particles***

Particles from people are dispersed:

1. From their skin
2. From their normal outdoor clothing
3. From their Clean Room clothing (both *through* it and from the surface).

The mixture of skin flakes and fabric fibers fragment into smaller pieces, so that the *total* number of particles is:

- 10 BILLION EVERY 24 HOURS. This figure is dependent on activity rate, more activity, more particles.

Demonstrations have indicated that typically this means:

- 1 MILLION PARTICLES EQUAL TO OR GREATER THAN 0.5 MICRONS ARE DISPERSED EVERY MINUTE.

They disperse into the air from exposed skin, through the apparel fabric and also out through the neck, waist, trouser opening and wrists.

Typical particles in semiconductor class 100 room air

Source	Percent
Human	46
Dust-Free Garments	8
Clean Materials	4
Photoresist Pieces	12
Silicon, Quartz	22
Other	8
<b>TOTAL</b>	<b>100</b>

*Other Particle Sources*

From the table it can be seen that roughly 50% of particles are caused by people. In "other" and "cleaning materials" will lie the content attributable to "yesterday's dirt" from the floor, walls, worktop and equipment surfaces - which is why some high-tech companies continually janitorially clean the Clean Room.

**What are the objectives in cleaning a Clean Room?**

The objectives in cleaning a room can vary between industries but the types of contamination that should be removed may be one, two or all of the following types:

- A** Particles and Fibers
- B** Chemicals
- C** Bacteria
- D** Electrostatic Charges

In all types of Clean Rooms particles and fibers are undesirable although the minimum size of particle which is undesirable will vary. In the electronics and optical industries, very small particles will cause malfunction of the product and in the pharmaceutical and medical devices industries it is thought unwise to introduce particles into the patient.

In all Clean Rooms, spillages of chemicals from one part of the process may be undesirable in another part of the process. The pharmaceutical and medical devices industries are very concerned with bacteria because of the danger to patients but the microelectronics industry is also concerned with bacteria because of their high ion content.

The microelectronics industry is concerned with static electricity because the discharge of very small voltages can destroy silicon chips. Many of the surfaces of Clean Rooms are poor

conductors, i.e. plastics, and can develop and retain a high electrostatic charge. It may be necessary to clean these surfaces in such a way as to leave a film of antistatic agent to conduct the charge away.

<http://www.mvent.com.ph/references/cleanroom.htm>

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### **What is PVD?**

The acronym PVD stands for *physical vapor deposition*. The deposition part is easy enough to understand, but exactly what do we mean by physical and vapor?

The term physical refers to the binding energy involved in the process. Binding energy can be thought of as a measure of how difficult it is to perform the process. We have a situation where some force or forces are holding two or more things together and we want to tear them apart.

The term *vapor* is another of those terms in common use. We all think we know what they mean, but often, when we get pinned down, we realize that the understanding we have is somewhat imprecise. Vaporization refers to the change of state from a liquid to a gas so, for example, the energy of vaporization determines the boiling point. Here, however, we are only using the term to say that before the deposition takes place, the molecule was in the gas phase rather than a solid or liquid phase.

Evaporation is one form of physical vapor deposition. For all evaporation processes, the driving force is heat.

As the temperature is increased, the material to be deposited first melts and then evaporates, entering the gas phase. Since a liquid has a definite volume but no definite shape, the material to be evaporated, called the evaporant charge, must be contained, like in a crucible.

The crucible is generally at a temperature greater than that of the evaporant charge. This limits the choice of crucible materials severely. There are a number of reasons for this.

- The crucible must not contaminate the evaporant charge
- The crucible must not be chemically attacked by the evaporant charge *at the operating temperature*
- The crucible must be able to remain physically intact, preferably through repeated cycles from room temperature to the working temperature for evaporation. [Remember thermal expansion and the fact that materials expand and contract at different rates!]

If you want to evaporate a noble metal, such as gold, this isn't too serious a problem. If you want to evaporate aluminum, it is quite another matter. Molten aluminum is vicious stuff! Then, there is tungsten, with a melting point of about 3410° C.

*E-Beam Evaporation* goes a step further. In this technique, a powerful high voltage electron beam is focused tightly upon the evaporant charge, which is held in a water-cooled crucible. The power flux in the beam is very large, so the immediate area where the beam strikes is heated

dramatically. Since the rest of the evaporant charge is held by a water-cooled crucible, however, it usually remains well below the melting point of the evaporant. This results in a phenomenon known as skulling. This term is used to describe the fact that the evaporant charge melts only where the beam impinges, and so forms a "skull-like" virtual crucible within the actual crucible of the electron beam gun. Thus, e-beam evaporation has some of the properties of flash evaporation with little of the mess. Such devices can even evaporate tungsten. Thanks to secondary electrons, they can even evaporate most insulators.

Electron beam sources for thin film deposition have beam powers in the range of a few kW to a few tens of kW. Pierce-type electron guns are used for metallurgical applications, and may have beam powers of 100 kW or more.

<http://www.cougarlabs.com/pvd1.html>

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At the ideal vacuum condition ( $10^{-6}$  torr), metallic molecules are free to travel towards the surfaces which have to be coated without encountering air or gas particles resistance.

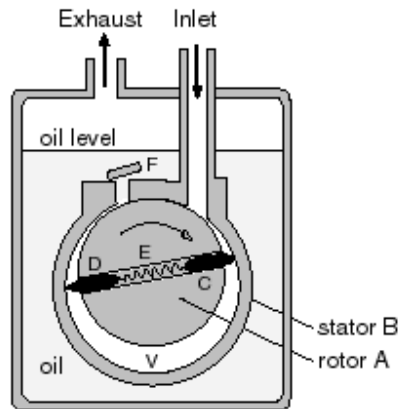
<http://www.kolzer.it/indexe.htm>

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## **Mechanical Pumps**

There are two mechanical pumps on many high vacuum systems. One is dedicated to pumping out ("backing") the diffusion pump, and the other serves to evacuate the sample chamber during initial pump-down prior to opening them to the diffusion pump. Mechanical pumps work at a rate of about 12 m<sup>3</sup>/h and maintain a backing pressure of about 25 millitorr on the diffusion pump.

Mechanical pumps operate by rotation of an off-center cylinder (Figure V-1). First, the pump takes in air from volume to be pumped with air molecules sucked in by depressurization caused by rotation of the cylinder. Next, the volume to be pumped is isolated by a valve (C and D in Figure V-1) and some air is admitted into the pump as a "carrier". The "carrier" and pumped air are compressed by continued rotation of the cylinder and vented through the oil to the outside. The process repeats until there is inadequate pressure to open the exhaust valve (F in Figure V-1).

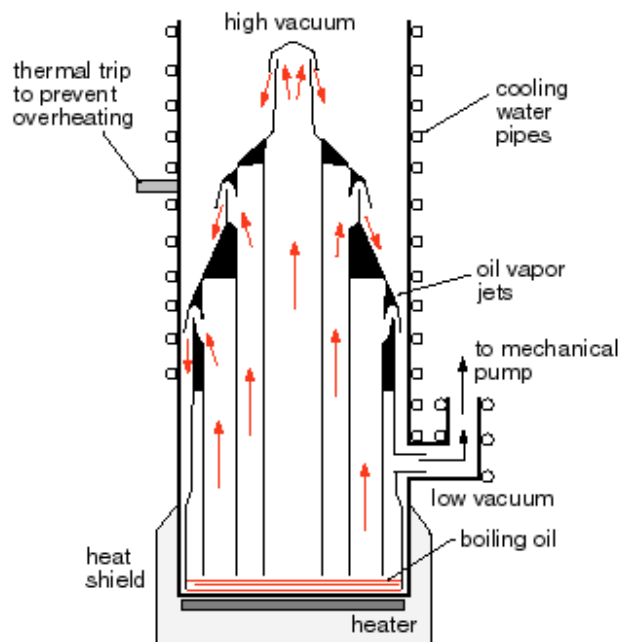


**Figure V-1.** Schematic diagram of a mechanical rotary pump (after Potts 1987).

### **Oil Diffusion Pump**

The diffusion pump is used to produce and maintain low pressures in the sample chamber. An oil diffusion pump requires a forevacuum of about 50 millitorr (5 to 10 Pa) to operate. Therefore, it is isolated from the sample chamber by a "gate" valve until the mechanical pump has produced a sufficiently good vacuum in the chamber.

A diffusion pump operates by boiling oil at the base of the pump that rises as a hot vapor. As it rises, it is directed into a funnel-shaped set of baffles and jetted as a supersonic vapor towards the cool walls of the pump. The oil cools and condenses, grabbing onto air molecules and dragging them down as it sinks (Figure V-1). Air is released from the oil at the bottom of the pump by the heater and is pumped away by the mechanical pump. The diffusion pump produces a working pressure in the sample chamber of about  $1 \times 10^{-6}$  Torr.



**Figure V-2.** Schematic diagram of an oil diffusion pump. Red arrows indicate the movement of boiling oil vapor (after Potts 1987).

<http://jan.ucc.nau.edu/~wittke/Microprobe/Pump.html>

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“There are two general ways for a vacuum pump to operate: it can remove gas particles from the pumped vessel and expel them to atmosphere by compression, or it can condense particles out of the pumped vessel by binding them to a solid surface (either chemically or because the surface is cold). The first kind (the compression or gas transfer pump) is far more common, in both everyday applications and research labs; the second (the entrapment pump) is mostly used in research labs.

Gas transfer pumps also work by moving gas from the pumped vessel to the outside world, but they do it without changing the volume along the way (i.e., without mechanical compression). Turbomolecular pumps draw gas from the vessel into a chamber with a rapidly spinning (tens of thousands of rpm!) series of blades, typically a few mm in size. When the gas molecules collide with the blades, they are driven from the inlet toward the outlet of the pump by simple momentum transfer. The blades change in size and shape from inlet to outlet to facilitate further movement. Simply by these collisions, the gas molecules get compressed until they reach the outlet pressure and are expelled from the pump(\*).

(\*) Turbomolecular pumps and diffusion pumps do not operate at outlet pressures of one atmosphere like rotary vane and piston pumps. Rather, they expel gas when it reaches a pressure of a few thousand times *below* atmosphere. Consequently, they must be "backed" by a secondary pump that can take the expelled gas at this low pressure and transport it to atmosphere. If this

doesn't make sense, don't worry about it; it's a detail. The basic principle of diffusion pumps and turbo pumps is that same as that of rotary vane/piston pumps.

In a cryopump, the inside of the pump is very cold, and the gas molecules from the warmer vessel stick in the pump, literally like water from your hot shower sticks on the cold mirror. Periodically, cryopumps must be "regenerated," which means warming them up and letting all the trapped gas come out.

There are other pumps-- such as Roots pumps and diaphragm pumps-- Which work by the general principles described for the more common pumps.

Pressure is often measured in units of "torr," where atmospheric pressure is about 760 torr. Even a little mechanical pump can easily achieve a pressure of 0.01 torr, and some can go as low as 0.001 torr (1 mtorr). The fancier pumps-- like turbomolecular, diffusion, and cryopumps-- can get to  $10^{-6}$  torr quite easily, and as low as  $10^{-12}$  torr under the best conditions. Massive Roots pumps, which I didn't discuss in detail, can get to  $10^{-15}$  torr. For comparison, outer space is a vacuum of about  $10^{-20}$  torr (roughly one molecule per cubic centimeter). Clearly we can't even come close to competing with Mother Nature!"

Network of Emerging Scientists, <http://psyche.uthct.edu/nes/nes.html>