Educational Guide to Vacuum Coating Processing

SVC
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Vacuum Technology:

Oil Diffusion Pumps

The oil diffusion pump (often called the "diff pump" or "DP") is probably the most widely used high-vacuum pump. It is very reliable and long-lived, although when misused it can create a great deal of contamination in the processing chamber. Figure 1 shows the cross-section of a typical oil diffusion pump. The pump oil in the oil sump is heated to where it has an appreciable vapor pressure and the heavy-molecular-weight oil vapor is directed toward the foreline by the vapor-jet elements of the diffusion pump. The vapor jets entrain gas molecules and direct them toward the foreline port, where they are pumped away by the backing pump(s). The oil vapors are condensed on the cooled pump walls and flow back into the oil sump. The oil diffusion pump is most effective in the pressure range of 10^{-3} to 10^{-9} Torr and the diffusion pump has the highest pumping speeds for the lightest gases.

Important oil-diffusion-pump operating parameters that should be continuously monitored or periodically checked are:

- inlet gas pressure (i.e., chamber pressure)
- foreline pressure near the pump outlet
- type and purity of the diffusion pump oil
- oil-sump temperature, which depends on the type of pump oil (i.e., the sump heater power)
- oil level in the sump—specified level +/- 30%
- pump-housing temperature and temperature gradient, which is determined by the coolant water-flow rate and the inlet and outlet water temperatures

The pump housing is generally water-cooled and the temperature gradient of the pump housing is important. In particular the upper housing temperature should be low to minimize re-evaporation and surface creep of the pump oils. The outlet manifold temperature should be low to prevent loss of pump fluid to the backing pump. The system can be interlocked and alarmed so that if the housing temperature rises above a set level, the high-vacuum valve automatically closes to prevent oil contamination of the processing chamber. Low oil level or low oil temperature will lead to a degraded pump performance during pumpdown.

Diffusion pump oils can be either hydrocarbon oils, silicone oils, or the very expensive perfluorinated polyethers (PFPEs). Silicone oils are the most widely used pump oil in PVD processing and are fairly stable to oxidation. The relatively inexpensive hydrocarbon oils easily oxidize and form varnish-like coatings in the pump, leading to maintenance problems. The PFPE fluids are extremely stable to oxidation and many strong acids and bases. They are used in reactive-deposition processes, plasma-etching processes, and low-pressure

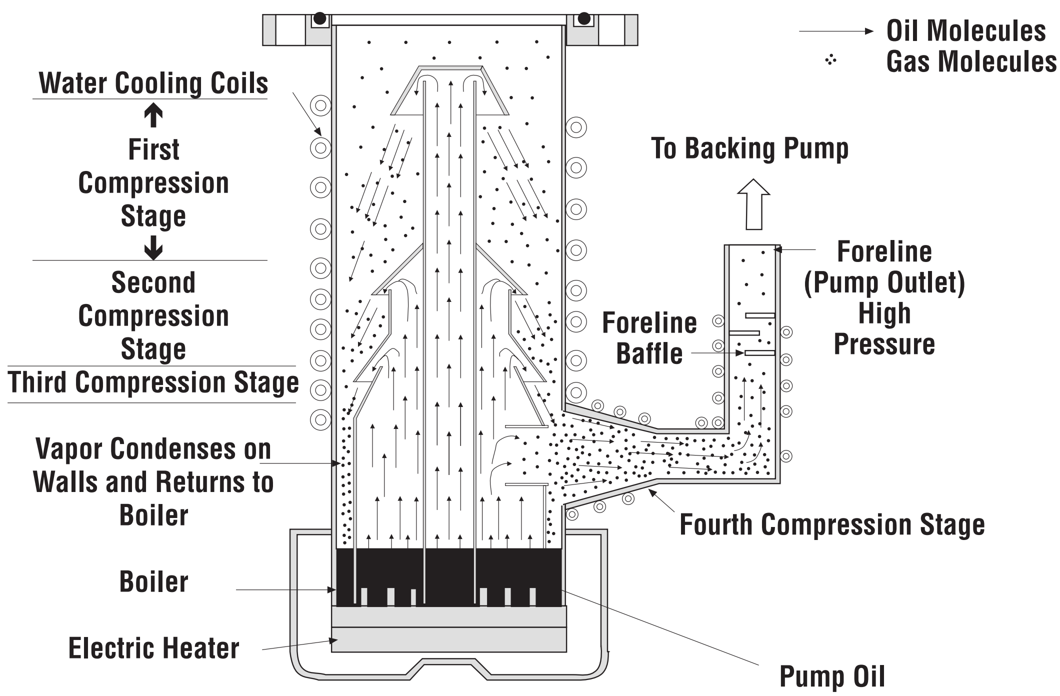

Figure 1: Cross-section of a typical oil diffusion pump. Adapted from *High-Vacuum Technology—A Practical Guide*, M. Hablanian, with permission.

Author: Donald M. Mattox, *SVC Technical Director*

chemical vapor deposition processing. Mercury can also be used as a pump fluid, but only for special applications because of its health hazards.

Care should be taken that the diffusion pump oil does not become contaminated by the hydrocarbon oils used in backing pumps for sealing and lubrication. Contamination can occur by backstreaming from the backing pump when the gas flow through the foreline is too low (molecular flow conditions) or when the foreline is allowed to "bleed back" to ambient pressure through the backing pumps. This problem can be prevented by the use of ballast valves or orifices to give a continuous (or emergency, when there is a power failure) gas flow into the foreline from the ambient. The diffusion pump oils can be used in oil-sealed mechanical pumps but their lubricity is low, creating increased maintenance problems.

Oil diffusion pumps can pump all gas and vapor molecules; but when pumping vapors that can be dissolved in the pump oil, the pumping speed can be lowered. When such vapors are to be pumped, a vapor-pumping "cryopanel" between the pump and the processing chamber can be used advantageously.

There is a critical mass flow through the diffusion pump above which the vapor jets will not perform satisfactorily. An important operational parameter is the "crossover pressure," which is the chamber pressure at which the roughing valve is closed and the high-vacuum valve is opened without raising the mass flow in the diffusion pump above its critical value for more than a few seconds. If the valves are operated at a higher pressure, there will be backstreaming of pump oil into the processing chamber due to the collapse of the vapor jet(s). The crossover pressure for the diffusion-pumped system varies with the diffusion-pump design and the size of the backing pump. The high-vacuum valve should be opened slowly to minimize the pressure surge in the diffusion pump.

If the chamber pressure is too low before closing the roughing valve and opening the high-vacuum valve, backstreaming can occur through the roughing line. Therefore the crossover pressure should be as high as possible. If backstreaming through the roughing line is a problem, an in-line trap may be included in the roughing line. This "roughing trap" will require periodic maintenance.

The diffusion-pump manufacturers specify the allowable foreline pressure as determined from backstreaming measurements. The foreline pressure should be continuously monitored near the diffusion-pump outlet and not be allowed to rise above the critical pressure for more than a few seconds. If there is a power failure, the foreline valve should automatically close to prevent the foreline pressure from rising above the critical value. The interlock system should be designed so that the foreline valve cannot reopen until the foreline pressure is below the critical value.

In order to reduce backstreaming between the diffusion pump and the processing chamber, baffles and traps may be used. A baffle is a plumbing component consisting of surfaces, cooled by chilled water, that prevent an optical line-of-sight between the pump and the chamber and condense the oil vapor and allow it to flow back into the pump. A trap is placed above the baffle and is cooled to a much lower temperature than the baffle by liquid nitrogen (-196°C) or a refrigerant (to -150°C). The trap also condenses water vapor and hydrocarbons from the processing chamber (much like a Meissner trap) and these vapors will be released when the trap is "warmed up." Traps and baffles should be cooled before the diffusion-pump oil is heated and before the high-vacuum valve is opened. The use of baffles and traps decreases the backstreaming into the process chamber but also decreases the pumping speed of the diffusion pump.

In the case of power failure, the high-vacuum valve should automatically close and remain closed until the trap and baffle have been cooled, the diffusion pump reheated, the chamber pressure decreased to the crossover pressure, and the foreline pressure is below its critical value.

Diffusion pumps are built in many sizes, ranging from as small as a 2-inch-diameter inlet throat to greater than 48 inches. Pumping speeds are about 6 liters/sec per cm^2 of inlet area. In operation, the backing pump can be used as the roughing pump with the foreline valve closed if only a few minutes are needed for rough evacuation of the process chamber. If a longer roughing time is needed, a "holding pump" is used to continually pump the foreline port of the diffusion pump while the foreline valve is closed.

Periodic maintenance of the oil diffusion pump includes:

- periodically changing the oil
- periodically removing and cleaning the internal vapor-jet elements
- periodically checking the temperature of the oil in the boiler
- periodically checking the temperature of the pump housing.

The sensitivity of the process to contamination and the potential for contaminating the processing chamber and fixturing with pump oils are considerations in determining what type of high-vacuum pump to use for the PVD processing. If contamination is a major concern, a cryopump or a turbomolecular pump can be used instead of a diffusion pump. The potential for contamination from these pumps is much lower than from a diffusion pump, although their cost is significantly higher.

References:

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