VACUUM PUMPING SYSTEMS FOR HANDLING THE
AGGRESSIVE GASES PRODUCED IN PLASMA PROCESSES

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In the production of semi-conductor devices there is a requirement to maintain a vacuum while pumping corrosive gases and in some cases abrasive particulates. The vacuum normally required is in the range $10^{-3}$ to a few millibar depending on the type of process. To reliably pump the corrosive gases at these pressures it is necessary to ensure the mechanical pumps and their accessories are suitable for this environment. It is intended to review the design of pump, the materials of construction and the special type of accessories that are required for this duty.

The relative merits of the types of fluid normally used in these pumps are discussed. The method of operation and the precautions that must be taken are also reviewed.

Finally, pumping units are described that incorporate all the features that are required for trouble-free operation.

PUMPING SYSTEM REQUIREMENTS

The table indicates that most of the processes met in semi-conductor production can generate pumping loads of noxious and unpleasant character. These consist of a mixture of process gases and reaction products. They may contain toxic materials, explosive materials, highly reactive and corrosive materials, sludge-forming materials and abrasive powders with a sub-micron size particle content. Pumping systems for such loads should be designed:

(i) to limit the entry of contaminants, particularly of abrasive materials into the pump,

(ii) to control the attack of aggressive or abrasive contaminants on the pump structure or the pump oil,

(iii) to prevent the accumulation of sludges or lacquers which can interfere with the pump function,

(iv) to minimise the danger of fire or explosion in the pump system,

(v) to permit safe disposal of toxic or reactive effluent from the pump.

PUMP OILS FOR PLASMA PROCESS APPLICATIONS

Oils are employed as lubricants and sealing fluids in mechanical pumps. They come into intimate contact with the pumping load and it is convenient to review their characteristics before dealing with pumping systems.1
Oils containing anti-acid and anti-oxidant additives are not normally used since their use is generally undesirable where large amounts of aggressive chemicals may be encountered. This is because reactions between chemicals and additives can cause heavy sludging and also because the activated filters often employed to remove aggressive chemicals are also effective at removing the additives soon after the pump is started.

When general-purpose hydrocarbon oils are used for aggressive chemical loads, chemical attack on the oil must be accepted as inevitable and contaminants and reaction products must be periodically or continuously removed. If this is not done, the rate of oil degradation will increase because some reaction products are acidic and reinforce the chemical attack. Periodic removal involves draining, flushing and refilling the pump. Continuous removal involves circulation through an appropriate (usually external) filter system. In this case the filter elements must be periodically replaced.

The distilled hydrocarbon oils (e.g. Inovil TW) are more costly than general-purpose oils but have the advantage that the lighter fractions, which break down more readily under chemical attack, are much less abundant so that chemical breakdown is less rapid. Also the initial vapour pressure is lower than with general-purpose oils - so that more degradation can occur before ultimate vacuum is too greatly affected.

The hydrocarbon oils in general are much less costly than the synthetic oils, which encourages their use in the larger pumping systems, but they should not be used when a significant amount of oxygen is present in the pump load. In this case the fully halogenated oils are the only completely safe pump oils available.

The ultimate pressure obtainable by rotary pumps using synthetic fluids are somewhat higher than can be obtained with clean hydrocarbon oils, but are quite adequate for plasma process applications. The fluorocarbon (Y VAC 06/6) yields the better ultimate vacuum of the two and has favourable viscosity characteristics which ensure easy cold-weather starting together with good lubrication and sealing at working temperature.

The synthetic oils resist chemical attack and so offer no sacrificial protection to the pump. They are non-detergent. They do not form strongly adherent films to protect the pump structure. The chloro fluorocarbons (e.g. HV40) will form solutions with common solvents, apart from this the halogenated fluids are only miscible with contaminating fluids by emulsification. This does occur so that the oils can carry fluid contaminants as well as fine dust contaminants suspended in them as they circulate. The halogenated fluids have high densities so that some contaminants may float on the fluid surface in the pump oil reservoir. Because of these considerations, contaminants should not be allowed to accumulate in the pump.

Gas ballast is sometimes sufficient to control accumulation, but its use is accompanied by continuous efflux of expensive fluid in the form of mist. This can be caught in a mist filter for eventual re-use. In more severe situations, external purification systems are used to remove contamination. The halogenated fluids themselves are not attacked and should last indefinitely.

OIL SEALED ROTARY PUMPS AND ACCESSORIES

Oil sealed rotary pumps are used for pre-pumping and/or backing duties in association with the mechanical booster pump. They are also used extensively on their own to provide vacuum for the medium vacuum processes.
in Table I.

The pump mechanisms employ large amounts of oil for lubrication and sealing and employ sliding surfaces in rubbing contact. Aggressive vapours entering the pumps are concentrated by compression and may dissolve in the oil or condense and emulsify with the oil. Abrasive powders may cause rapid wear. Flammable or explosive gas mixtures may present a serious hazard after compression.

If the oil is chemically attacked, the breakdown products can include acidic materials which accelerate breakdown and sludgy or gummy materials which may clog oilways or strainers or hinder the free movement of the mechanism. Aggressive materials carried in the oil can attack the fabric of the pump.

Field experience has confirmed the expectation that the best way to protect the pump fabric from abrasive wear and chemical attack is to preserve as far as possible the cleanliness and quality of the oil while ensuring that the pump is provided with a generous flow of oil under all operating conditions. The oil will then keep the pump internal surfaces washed clean and it will be unnecessary to employ specially resistant materials for the main pump structure. It, of course, remains desirable for small sensitive parts to employ well chosen materials: e.g. Viton rubber for dynamic seals and valve pads, stainless steel for springs, strainers and light metal parts, corrosion-resistant plastic for blades. Many pumps employ such materials as standard.

A generous oil flow under all conditions is best assured in the pump incorporates its own oil pump. Figure 1 illustrates such a pump, at (2) the oil pump delivers oil to a spring-loaded distributor valve (3), from which the oil flows into the vacuum pump mechanism at controlled pressure. In the pump illustrated the oil enters the oil pump through a mesh strainer (1) and the distributor valve diverts a proportion of the oil flow through a fine pore by-pass filter (8) to remove solid contamination. In severely contaminated conditions it has been found that gummy materials can accumulate on the strainer and gradually block it, thus starving the pump of oil. The danger is overcome by providing a strainer of extra large size and an oil pressure gauge or switch to give warning if oil feed pressure to the oil pump falls too low. Some pumps have built-in connecting points for such a gauge or switch.

Internal filters, like that illustrated at (8) in figure 1 have limited capacity and are not of a type capable of neutralising or trapping acidic and corrosive fluids. In severe conditions it is effective to provide a large external filter system and in some cases omit the pumps own filter. Filtration media (e.g. activated earths or hydrophilic fabrics) can be provided which trap solid particles and gummy deposits and neutralise or absorb aggressive materials. With some filter types the vacuum pumps's own oil pump can maintain adequate oil flow. In other cases the filter unit can incorporate its own oil pump and pressure gauge. This ensures a high enough driving pressure for compact filter units to be used. The smaller oil charge such units require is particularly necessary when costly fluorinated fluids are employed.

Oil filters can only remove abrasive particles after they have entered the pump mechanism. If the load contains much abrasive material it is sensible to prevent most of it from entering the pump by use of an inlet filter. Condensation in the pump of contaminating vapours can be prevented and their solution in the oil can be reduced by the use of gas ballast. The
ballast gas emerges from the pump discharge port laden with these vapours so that the load on any oil filtration system is much reduced. However, gas ballast provided by ordinary atmospheric air does nothing to reduce the hazard when flammable or explosive materials are being pumped, and may increase the hazard by providing oxygen and by producing a fine mist of oil droplets carried in the effluent gases.

The use of dry nitrogen as ballast gas is increasing and is proving very effective at preventing accumulation of aggressive materials in pumps and at diluting flammable or explosive gases, vapours and mists in an inert carrier gas. Accessories are available from pump manufacturers for the convenient provision and control of dry nitrogen gas ballast and also dry nitrogen flushing of the oil box. The use of dry nitrogen is emphasised because many of the corrosive materials being pumped show increased activity in the presence of water vapour.

The use of gas ballast is always accompanied by the loss of oil from the pump in the form of fine mist carried in the effluent gas. The mist droplets can be caught and down-stream oily pollution prevented by the use of a mist filter at the pump outlet. The filter will only catch liquid droplets, so aggressive vapours pass through it with the ballast gas; however, it should be lagged so that it becomes warm and condensation of the aggressive vapours is prevented. Clean oil retained in the mist filter may be reusable.

It follows from the above that the process operator must provide suitable traps or lead-ways downstream of the pumping system to prevent environmental pollution by chemical gases and vapours.

Ultimately the most probable failure is due to damage to the shaft seal normally caused by the residual particulate. The physical properties of fluoro-carbon oils are such that it will leak through a shaft seal more readily than the standard hydrocarbon oils. A solution to this problem is to adopt a double shaft seal arrangement as shown in figure 2. The inner seal is a positive action PTFE seal while the outer is a normal PTFE lip seal. Dry nitrogen is bled into the space between the two shaft seals and then via a restriction to the gas ballast inlet of the pump. Normally, the pressure in this space is 0.2-0.3 bar gauge and even with a damaged seal with this positive pressure oil leakage is unlikely. If, however, any oil does pass the first seal it is then entrained and returned by the gas ballast flow into the gas ballast inlet. The return line is translucent so that any oil returned is visible and preventive action can be taken. A solenoid valve in the inlet to the gas ballast assembly ensures that this circuit is closed when the pump stops.

CONCLUSION

Rotary vacuum pumps sometimes in conjunction with mechanical boosters and fitted with appropriate accessories are running reliably on the complete range of production processors associated with semi-conductor device manufacture. In particular, the use of dry nitrogen gas ballast, inert fluorinated fluids and the continuous cleaning of these fluids gives reliable operation even in the most aggressive duties that are encountered in the production of semi-conductor devices.

References
5. Patent application no. UK2140102A
<table>
<thead>
<tr>
<th>PROCESS</th>
<th>COMMON PROCESS GASES</th>
<th>VACUUM CONDITIONS PRESSURE (MBAR)</th>
<th>FLOW (MBAR 1s⁻¹)</th>
<th>COMMENTS</th>
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</thead>
<tbody>
<tr>
<td>Crystal growing Deposition</td>
<td>Ar, He</td>
<td>1-50</td>
<td>1-50</td>
<td>Abrasive particles.</td>
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<td></td>
<td>B₂H₆, AsH₃, PH₃</td>
<td>0.1-5</td>
<td>1-30</td>
<td>Gas load contains abrasive particles.</td>
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<td></td>
<td>SiH₄, SiH₂Cl₂, NH₃</td>
<td></td>
<td></td>
<td>Gases entering pump can be highly explosive and toxic.</td>
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<tr>
<td></td>
<td>N₂, O₂, H₂</td>
<td></td>
<td></td>
<td>Ion source provides biggest hazard to pump.</td>
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<tr>
<td>Ion Implantation (ion source)</td>
<td>BF₃BCl₃, AsH₃</td>
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<td></td>
<td>PH₃, H₂, Ar</td>
<td></td>
<td></td>
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<tr>
<td>Epitaxial deposition</td>
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<td>0.5-5</td>
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<td>Abrasive particles.</td>
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<td></td>
<td>SiH₂, SiH₂Cl₂</td>
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<td>Toxic gases.</td>
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<td></td>
<td>H₂, N₂</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>(CCl₄, CF₄, CCl₂F₂)</td>
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<td>(BCl₃, N₂, O₂)</td>
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<tr>
<td></td>
<td>(H₂, Cl₂)</td>
<td></td>
<td></td>
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<tr>
<td>Plasma desmear</td>
<td>CF₄</td>
<td>0.3-1</td>
<td>1-15</td>
<td>Vapour causes rapid corrosion of pumps and accessories via HF attack. Oxygen safe oil must be used.</td>
</tr>
</tbody>
</table>

**FIGURE 2**

Double rotary seal arrangement employed in rotary pumps for very corrosive duties.

1. Pressure regulator.
2. Flow meter.
3. Pressure gauge.
4. Fixed restrictor.
5. Magnetic valve.
FIGURE 1

A representation of the oil system of a 40/80m³/hr. single stage pump.

1. Inlet strainer.
2. Oil pump.
4. Oil feed to pump.
5. Oil feed to oil operated gas ballast shut-off valve.
6. Excess oil returns to reservoir.
7. Oil feed to filter.
8. Oil filter.
9. Filtered oil returns to reservoir.
10. Wide-range oil level sight glass.