Lubricants for Semiconductor Manufacturing Equipment

By Kevin Akin and Dan Shea

Ultrafiltration of oils and greases removes microscopic contaminants from oils and greases and homogenizes agglomerated thickener in grease. Coupled with strict control of vapor pressure, this "super cleaning" process helps ensure that lubricants do not compromise the performance of sensitive devices in vacuum or clean room environments.

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While speed, uniformity, and cleanliness have made automated assembly equipment the norm in semiconductor manufacturing, they also have posed a conundrum regarding lubricants. Oils and greases do help robots, pick and place stations, conveyors, valves, switches, and other devices on the production line run better and last longer. But they also contribute to airborne molecular contamination or worse, give off vapors that can fog optics in high speed inspection systems or even contaminate wafers.

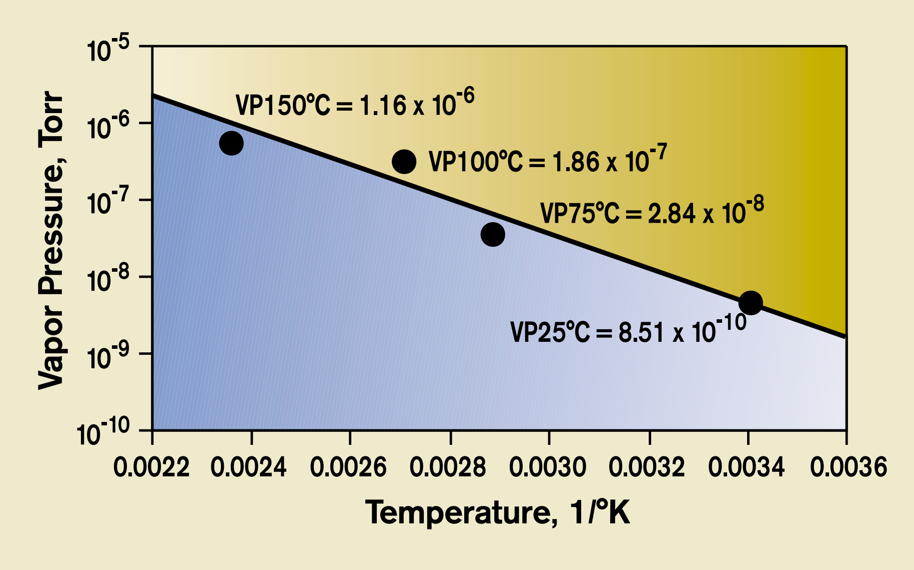
Lubricant-related problems, however, can be minimized or eliminated. Case in point: the aerospace industry has been working for decades on qualifying lubricants for mission critical components — addressing problems like lubricant outgassing, contamination, and starvation. Much of this research is now being applied successfully to designing lubricants for sub-assemblies in clean rooms, laboratories and semiconductor manufacturing facilities.

PRIMER ON LUBRICANT CHEMISTRIES

Lubricants reduce friction, the normal force of the adjoining materials multiplied by the coefficient of friction (μ), which is the resistance of the softer material to plastic deformation under shear and compression (μ=S/P). The addition of a lubricant between the contacting surfaces reduces the coefficient of friction, which reduces component wear and ultimately extends operating life.

Solids and liquids can be used as lubricants. Solid lubricants include graphite, molybdenum disulfide, and polytetrafluoroethylene (PTFE) powder. Easily abraded, solid lubricants, when used alone, are generally short-lived and not appropriate for long-life applications. The most common liquid lubricants are mineral and synthetic oils. Generally, all synthetic oils withstand broader temperatures and are more chemically homogeneous that their natural counterparts. Specific synthetic oils offer additional advantages, which are discussed below. Typically, oils are specified for flea-powered devices, where available torque will not overcome even the lightest grease. Grease falls in between solid and liquid lubricants. A semi-solid, it is an oil that has been immobilized with a thickening agent. Unlike oils which require tightly sealed reservoirs to prevent migration, greases rely on soap, clay, or solid-lubricant thickeners to keep the lubricating fluid where it is needed.

Choosing the proper lubricant for any application requires careful consideration of each of its ingredients, starting with the



Measuring Vapor Pressure

It is not practical to determine the vapor pressure of high molecular weight lubricants at room temperature, since trace outgassing would be extremely difficult to measure. So, Langmuir's equation is used to calculate vapor pressure at several elevated temperatures, and these values are used to extrapolate vapor pressure at 25°C.

base oil, the largest percent composition of any lubricant. General classes of synthetic base oil chemistries include: synthetic polyalphaolefins (PAOs), synthetic esters, silicones, multiply-alkylated cyclopentanes (MACs), polyphenylethers (PPEs) and perfluoropolyethers (PFPEs). Each brings different advantages to clean rooms and semiconductor manufacturing.

PAOs are generally the lowest cost alternative. They exhibit good antiwear characteristics and the ability to be fortified with traditional additives. However, at higher temperatures or where minimal outgassing is critical, PAOs don't always measure up.

Synthetic esters and silicones are both a step above PAOs in performance and cost. Because esters are highly polar in nature, they are intrinsically good boundary lubricants. Compared to PAOs, they offer lower vapor pressure and higher thermooxidative stability. However, esters should raise a caution flag. They are chemically reactive with a number of commercial polymers and elastomers, and they are susceptible to chemical breakdown in the presence of acids, bases, and certain metals. In either case, lubricant performance and the component can be seriously compromised.

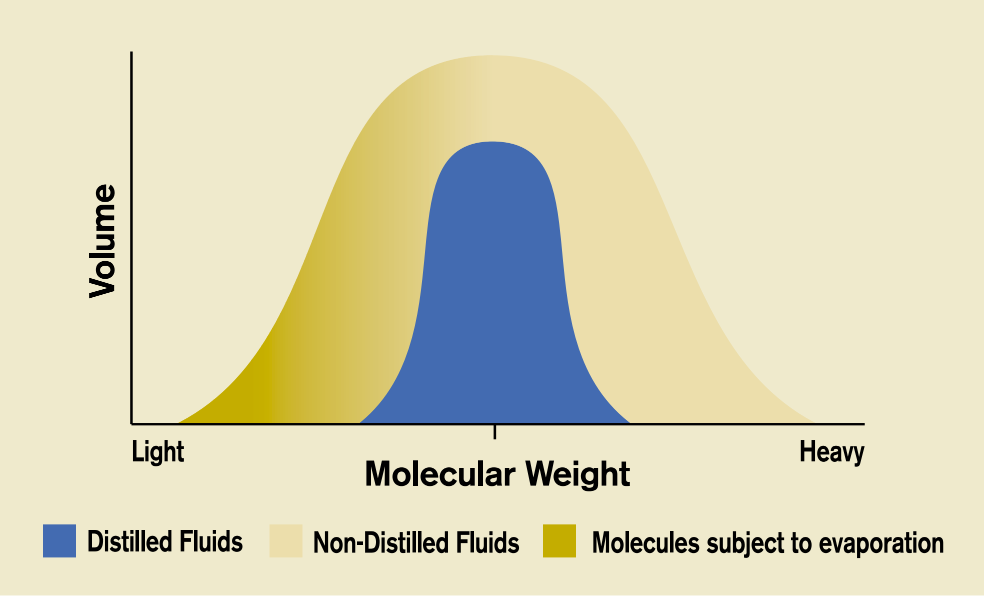
Silicones represent significantly improved performance over PAOs and esters. They have much wider service temperature ranges, excellent low volatility characteristics, and good thermooxidative stability. However, they are a very "compressible" molecule. While this characteristic is no problem in lubricating plastics and lightly loaded metals, silicones do not offer the same wear resistance as esters or PAOs in more highly loaded metal-on-metal applications.

MACs, PPEs and PFPEs — all high molecular weight materials — represent the very latest developments in synthetic chemistry for lubrication. While their prices are correspondingly higher, their unique properties make them well suited to the demands of semiconductor fabrication. MACs exhibit exceptionally low vapor pressure, can be readily fortified with application-specific additives, and offer good thermooxidative stability and chemical compatibility. PPEs come with a long history of use in lubricating electrical connectors. They offer excellent vapor pressure characteristics and the unique advantage of enhanced radiation resistance — one to two orders of magnitude better than that of other synthetic chemistries. Though not as robust as some other synthetic chemistries under boundary lubrication conditions, PFPEs are already well known in vacuum-critical applications, especially when low vapor pressure, wide temperature, chemical inertness, and material compatibility are important.

FOCUSING ON SEMICONDUCTOR AND CLEAN ROOM LUBRICANTS

While every lubricant should be designed to meet temperature, load, torque, and other device-specific requirements, lubricants for vacuum or clean room applications also have to meet rigid vapor pressure standards. Vapor pressure is the force per unit area exerted by molecules that have entered the gas phase on an imaginary surface immediately above the liquid surface. In lubrication design, this property is very useful in comparing the tendency of different oils or other lubricant components to become volatile, which increases the potential of contamination from evaporative loss. Thus, the lower the vapor pressure, the better the lubricant.

The vapor pressure of a lubricant, which is measured in a vacuum, can be determined using Langmuir's equation: P = 17.14 G (T/M)1/2, where P is the vapor pressure in Torr, G is



Distillation and Evaporation Rates
When the range of molecular weights in a fluid is wide, the fluid is more volatile, since lighter weight molecules are prone to evaporation. Through additional distillation, lighter weight materials are removed. Though the original volume of the fluid decreases, the range of molecular weights narrows, reducing the likelihood of evaporation.

the rate of evaporation in grams per square centimeters per second, T is the temperature in °K, and M is the molecular weight of the material in question. When designing a lubricant, the surface area of the device to be lubricated (a factor of G) and the temperature of the operating environment are givens. So the above equation underscores the importance of molecular weight, a variable linked to the selection of the base oil, in designing a low-vapor-pressure lubricant. The best candidates for low outgassing are base oils with high molecular weights — materials like MACs, PPEs, and PFPEs. Further, since each molecule in a base oil can have a slightly different molecular weight, narrowing the range of molecular weights is better still. Through a special distillation process, lighter materials can be removed during lubricant manufacturing, instead of waiting for them to volatilize and contaminate on the job.

It is important to note that while most "vacuum lubricant" suppliers specify vapor pressure data, this data is seldom the result of measuring each lot of lubricant. Without close control, the vapor pressure of two batches of the same lubricant may be different — by several orders of magnitude. So, to best utilize vapor pressure data in determining a lubricant's outgassing potential, per-lot assays should be conducted.

In addition to selecting base oils with low vapor pressure and high molecular weight, particulate contamination control is another important criterion for lubricants in vacuum and clean room applications. During manufacture of the lubricant, dust, dirt, and even improperly dispersed thickeners can become entrained in an oil or grease. In rolling element bearings, for example, particulates or agglomerated thickener can rupture the elastohydrodynamic film that separates the balls from the raceway, scarring balls and raceway, which impairs performance and shortens operating life. In fact, with advances in material science, most bearing failures are attributed to lubricants. Generally, anything less than super-clean lubricants can compromise device accuracy, repeatability, and operating life.

Ultrafiltration can ameliorate these problems. A sophisticated pre- and post-production filtration process, ultrafiltration homogenizes thickener in grease and removes particulate matter as small as 1 micron from oils and 35 microns from grease (For reference, a grain of sand is about 650 microns). Since various military standards define lubricant cleanliness, ultrafiltration, at a minimum, tells the user the relative sizes of particles in a lubricant, and that information can be used to predetermine if this is detrimental to operation.

The semiconductor industry contains a vast array of electromechanical devices whose performance and operating life depend upon selecting the right lubricant. No one chemistry will suit all needs. However, somewhere among the various base oil chemistries, gellants, and additives available — combined with what has been learned about designing and manufacturing lubricants for vacuum and clean-room environments — the ideal lubricant exists for each and every component in the semiconductor manufacturing environment. ■