The Material Science of Seals: Part I

By Dalia Vernikovsky

This article is the first in a three-part series on high-technology sealing components used to create and safeguard ultraclean manufacturing environments.

Introduction

Twenty five years have passed since NASA's Challenger space shuttle was brought down by the misapplication of an o-ring, made with a Viton®[1] material that could not handle the extreme temperatures of the launch. While the tragic and heartbreaking loss of lives is incomparable, catastrophic failures of sealing products in semiconductor-processing environments can put at risk millions of dollars in wafer losses and costly equipment downtime.

How can seemingly innocuous O-rings have such a huge bearing on success or failure? If you stop to think about the thousands of O-rings utilized throughout a wafer fab—with so many types of equipment and their ultrapure environments housing dozens of processing steps—the pervasiveness and vital importance of seals becomes clearer. Consider the wide range of sealing components, which range from the O-rings, chamber seals and fittings within each tool to the gates, slit valves and doors on highly sensitive equipment used throughout the chip-making process (Figure 1). If these interfaces are not addressed as part of the ultraclean processing solution, they will certainly become part of the problem.

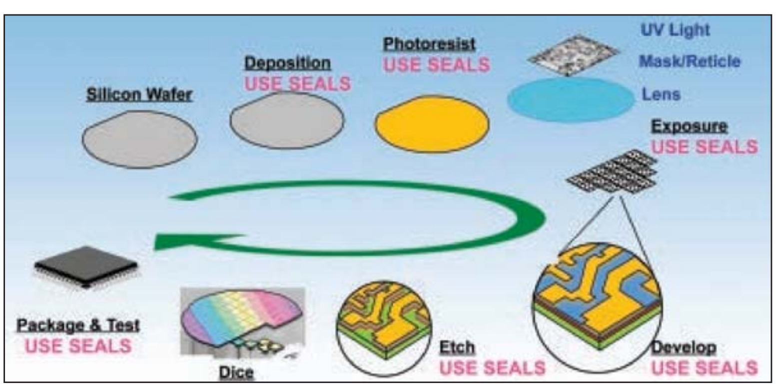

Figure 1. Seals are used throughout the chip-making process

Preserving Seal Performance

In a world where particles measuring 0.12 micron or less can cause killer defects, O-ring composition becomes a critical concern. Viton, the predominant material from which o-rings are made, is available in many variations.

O-rings have not changed from original formulas created in the mid-1900s.

Most varieties are made with fillers that are unacceptable in ultraclean processing—fillers such as magnesium oxides and silica-based additives that introduce large amounts of impurities to the process.

Over time, exposure to even the smallest traces of chemicals and gases can cause sealing components to wear and begin to break down. To the surprise of many technicians in the wafer fab, it is usually the cleaning gases used between all wet and plasma-based processing steps—not the deposition or etching chemistries themselves—that cause the most seal degradation. The problem lies in the harshness of the cleaning gases themselves, which are typically NF_3 or similarly aggressive fluorine or oxygen combinations. During cleaning, these gases literally blast the chamber walls to remove any residual radicals. Unfortunately, the cleaning gases also attack the chamber components, including seals, with significant force and energy.

Another reason for seals' susceptibility to damage from cleaning gases is that the physical makeup of O-rings has

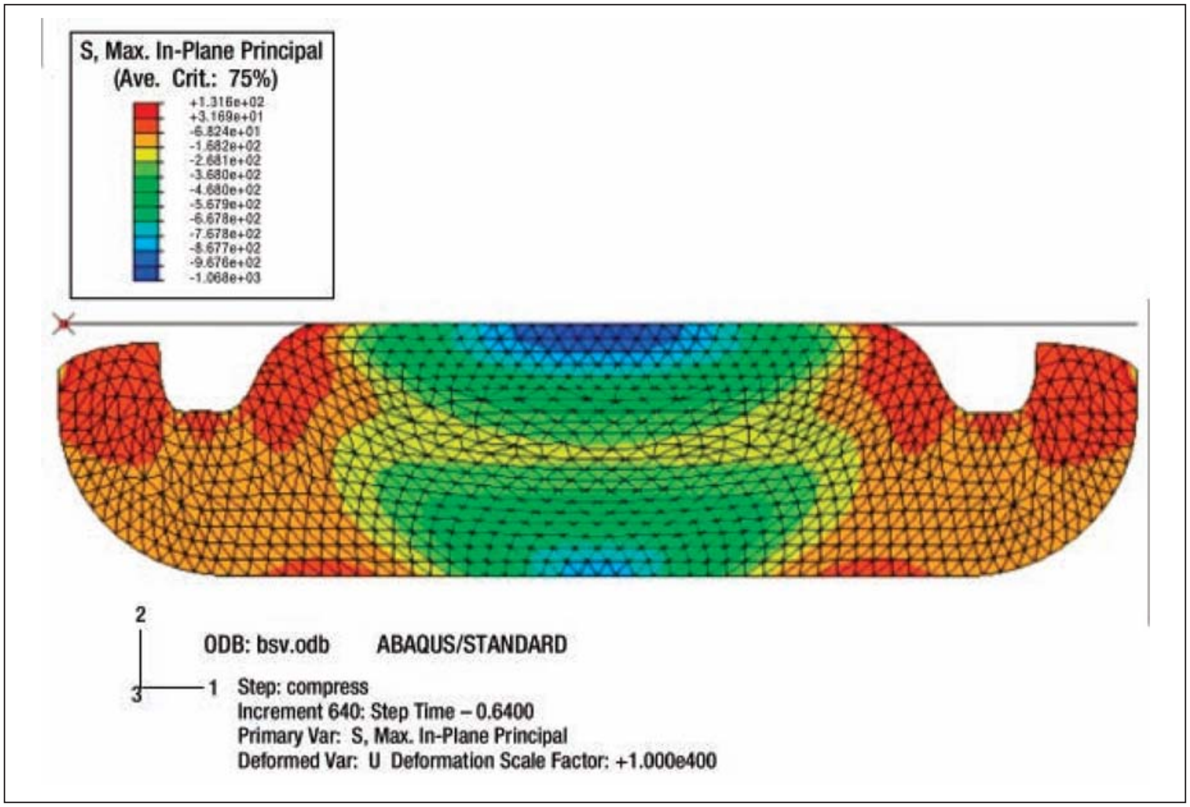

Figure 2. FEA computer generated mesh of a seal revealing stress points.

not changed fundamentally from the original formulas created in the mid-1900s. Even today, the majority of O-rings are made in industrial settings and carry with them all of the issues raised by non-cleanroom materials. O-rings were initially developed for industrial and, later, aerospace applications. For these markets, the seals had to withstand pressures of 500 psi and more. This led to the use of industrial-grade additives such as carbons, magnesium oxides and other fillers to create the needed strength and flexibility. At that time, the primary design criteria for O-rings were the abilities to withstand tugging, pulling and the dynamics encountered around rods and pistons. Early seals were never created to deal with significant contamination or vacuum requirements.

Finally, many sealing problems result when seal selection and usage is an afterthought. Users may know that a seal is needed, but too often little effort is made to review the performance requirements, restraints and physical demands that the installed seal will face. In many cases, seal providers or manufacturers are not consulted until problems arise. At that point, it is unreasonable to expect a quick-fix solution at little or no cost so that production timelines are not affected.

A smarter, more productive approach is to involve seal manufacturers earlier in the equipment-design process. This way, seal providers can apply their in-house expertise and tools to design a seal that fits each application, helping to avoid problems downstream. One key tool is a process called finite element analysis (FEA), which can verify seal performance before committing to custom tooling. FEA uses linear algebra and calculus to predict when a seal will fail when subjected to real-world stresses. A computer-model mesh (Figure 2) is generated to create a virtual seal, complete with material and structural properties. By subjecting the virtual seal to theoretical stresses and loads, seal designers can study potential problem areas and work to correct them before production begins. The FEA process is thorough, but complex, involving approximately 120,000 simultaneous calculations. But this advanced analysis of a seal's performance in its intended environment enables optimization of the seal's design, which can reduce the time needed for system maintenance, increase the time between preventive maintenance servicing and safeguard against contamination problems.

It's What's Inside that Counts

Awareness of contamination issues began to increase in the 1980s. To address these new needs, seal manufacturers began using perfluoroelastomers. These materials have unique chemical and thermal characteristics that can help to assure cleanliness and process integrity, but they also come with some distinct handling requirements.

In O-ring language, FFKM is a common term used to describe a perfluoroelastomer with a completely fluorinated, more inert backbone. When properly designed, seals made with FFKMs can exhibit longer useful lives with reduced outgassing, lower contaminants and greater thermal stability. Of all perfluoroelastomers, FFKMs can accommodate for the widest temperature ranges—from up to 230 degrees C for peroxide-cured FFKMs to over 280 degrees C for triazine-based FFKMs.

Unlike Viton, FFKM perfluoroelastomers have no exposed hydrogen positions (Figure 3). This helps to prevent chemical breakdown of the material, yielding cleaner and more durable seals. Although O-rings produced with FFKMs are chemically resistant, their carbon-fluorine backbones don't contain the fillers needed to strengthen these O-rings' mechanical properties. The fragile nature of FFKM O-rings requires that they be handled delicately without undue stretching. But from my own discussions with end users, these sensitive seals are mishandled and damaged during more than 50 percent of all installations. It is not only incorrect; it is dangerous for maintenance technicians to assume that all seals have the same physical properties. Wider understanding of the key differences among various perfluoroelastomers is needed throughout the global semiconductor industry. (Proper care and installation of different seals will be addressed in the next article in this series.)

As with perfluoroelastomers, there also are many variations among available fillers and curatives. Peroxide, triazine and bisphenol are the top three curatives, and each has its own pluses and minuses. Fillers such as $BaSO_4$ are used to help safeguard an O-ring's base polymer from exposure to the harsh plasmas used in semiconductor fabrication, which can eventually etch away part of the O-ring. As a side benefit, using a $BaSO_4$ filler with specific curatives can actually add some mechanical strength to FFKM material.

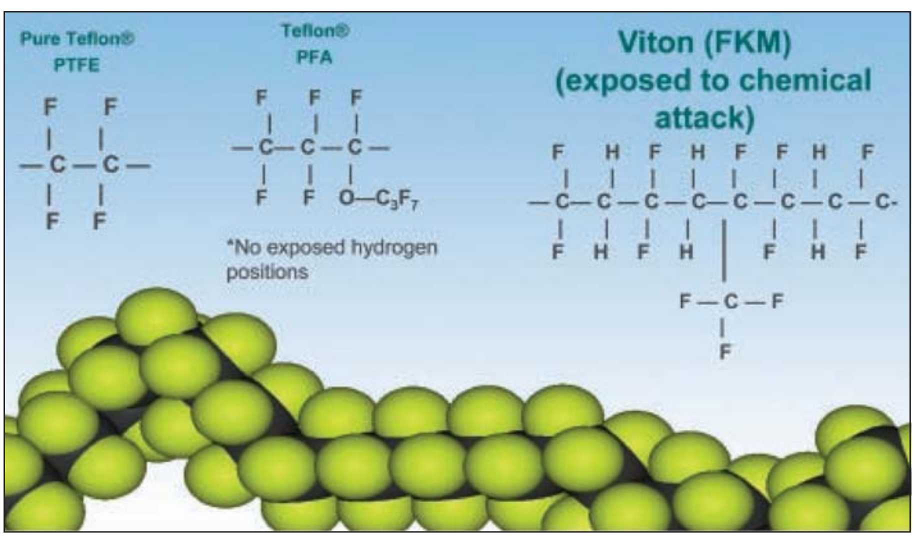

Figure 3. FFKM/FKM Polymeric and elastomeric structural units

But the affects of fillers often are not explained well enough to end users. For example, using a triazine-based O-ring developed for high temperatures risks significantly shorter lifetime, greater tool downtime and more lost productivity compared to using a peroxide-cure version with a filler specifically designed for such hash cleans as NF_3 cleans.

Seals made with FFKMs can exhibit longer lives with reduced outgassing.

When considering seals, even visual cues can be misleading. The semiconductor industry tends to favor seals made with $BaSO_4$ or TiO_2 fillers because the resulting seal is white, which some people automatically associate with cleanliness. On the contrary, these fillers will break down in wet-processing applications and risk introducing metals into the processing chambers in either wet or dry areas if not applied properly.

Just as the use of different fillers can cause variations in seals, there are subtle but important disparities among the products supplied by different seal manufacturers. The utter lack of standards for semiconductor-grade seals allows for potentially dangerous wiggle room among various formulations offered on today's market. Without accepted international standards, there is little or no assurance to users that the seals they are using will deliver consistent, reliable performance. The harsh reality is that this may lead to fab-wide manufacturing glitches that will cause downtime and reduced yield.

Clearly more communication and education is needed to select the optimal sealing solution that will protect the integrity of each manufacturing process and maximize performance.

Summary

Not all seals are created equal. Thermal, chemical and hardware considerations can greatly influence the type of seal needed for a specific application. Even within the family of perfluoroelastomer seals, there are variations in material composition that can determine if a seal is the correct choice for a given situation.

The people who will have daily responsibility for the installed seals – from maintenance technicians to facility managers – must be educated by knowledgeable seal providers about the variety of available products and why selecting the right solution involves much more than matching sizes and colors. When it comes to the materials science inherent in seals, the devil truly is in the details. (The next article in this series will address practical aspects of handling, installing and replacing seals.) G&I

1. Viton is a registered trademark of DuPont Performance Elastomers L.L.C. ,

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