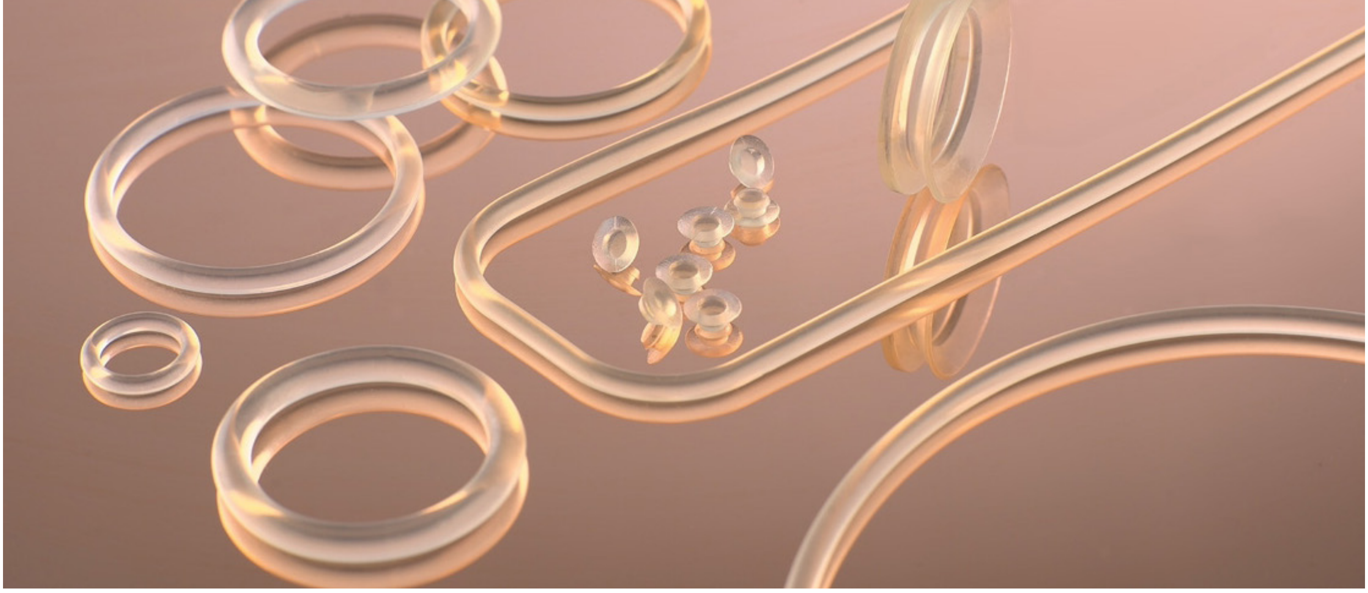
Critical Components: How Clean are your seals?

Knut Beekmann

Precision Polymer Engineering

www.prepol.com



Perlast® G67P high purity O-rings and sealing components

When working at the nano-scale of chip production, even the lowest trace metal levels have the capacity to alter the electrical characteristics of the device and/or affect the reliability of the end product.

Background

During routine operation, many components within the process tools and ancillary equipment will be subject to wear and abrasion, particularly those components within the process module that are directly exposed to harsh physical and chemical environments. The most critical locations are those where components are exposed to such environments and in proximity to the substrate being processed.

An equipment consumable item that can sometimes be overlooked is the elastomer seal or O-ring material. These seals have a certain lifetime proportional to the mechanical and chemical properties of the material and the physical constraints of the groove and location. Whilst an elastomer in a critical location may not actually determine the maintenance cycle of the process tool, byproducts and elastomer constituents will be released into the process environment during active operation. It is therefore clear that whatever is in the elastomer can contaminate the wafer and this applies equally to the trace metal content of the elastomer.

Trace metal contaminants fall broadly into two categories;

- alkali metals which include elements such as sodium (Na), potassium (K) and lithium (Li), and
- heavy metals which include elements such as copper (Cu), iron (Fe), zinc (Zn), titanium (Ti) and chromium (Cr).

The effects on the device of such contaminants vary depending on the type of the element. Sodium for example, can readily lose its outer electron to form an ion with charge +1. It can then readily diffuse through the oxide under the influence of an electric field even at room temperature. However, it cannot penetrate the silicon lattice which means that a charge can accumulate at the silicon/silicon dioxide interface. This in turn leads to unpredictable voltage threshold shifts and correspondingly random digital outputs from logic circuits.

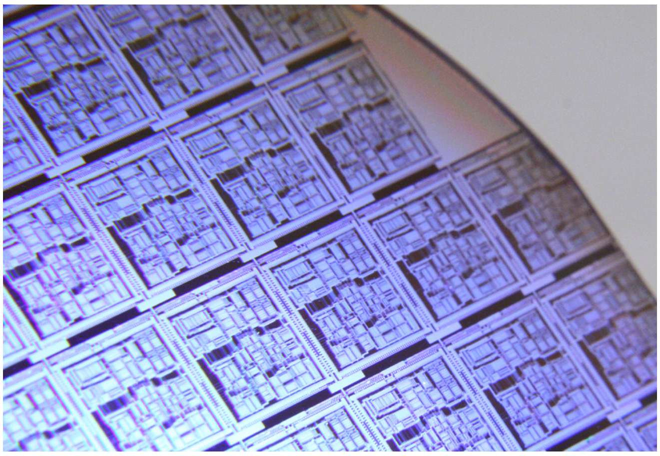
Additional failure mechanisms include current leakage through the dielectric and reduced dielectric breakdown voltage, degradation of time dependent dielectric breakdown (TDDB), or complete breakdown of the gate[1].

Gettering layers are also no guarantee of eliminating the issue. PSG and BPSG layers are often used to getter sodium ions however; the presence of moisture either through integral process steps or atmospheric absorption can facilitate the release of trapped mobile ions in the getter[2]. Rather than accumulate at the semiconductor interface, heavy metals tend to diffuse through the semiconductor, where they effectively create energy states in the bandgap of the semiconductor causing changes in carrier lifetime or the diffusion length[3].

PPE Precision Polymer Engineering

Consumer demands for faster, more powerful and portable technology with greater functionality is a key factor in driving the semiconductor manufacturing industry. Although the part of Moore's Law that refers to shrinking technology remains largely intact, the pressure on cost reduction is rising throughout the whole value chain[4]. Reduced device dimensions and gate thickness leads to devices that become more sensitive to a number of factors including trace metal contamination.

It is clear that such contamination leads to unstable device performance, yield loss, device degradation with increased risk of reliability failures, potentially costing the fab in lost time, loss of revenue and wafer production capacity.



Purity in elastomers

When choosing elastomer materials for seals in process tools, manufacturers must decide on the appropriate material in accordance with the location in the tool and the chemistry involved. Critical locations where the elastomer is in contact with the chemistry or process media, where degradation takes place, and where the byproducts of this degradation can be transported to the wafer, require the highest quality seal material in order to avoid contaminating the device. The sealing product must precisely fit the characteristics of the operating equipment.

Specialist sealing companies have significant experience and expertise in developing and customising elastomer seals and O-rings for use in semiconductor applications.

There is often a large choice of products for any one particular application and "semiconductor compatibility" is often taken for granted especially in critical applications however; not all elastomer materials are equal when it comes to the level of undesirable contaminants.

For many device applications, it is no longer adequate to measure contamination at the parts per million level. When analysing trace metal levels in elastomer materials, vapor phase decomposition (VPD) combined with inductively coupled plasma mass spectrometry (ICPMS) yields data down to parts per billion[5]. A number of different elastomer materials have been analysed by an independent test laboratory in order to quantitatively determine the amount of trace metal within each sample.

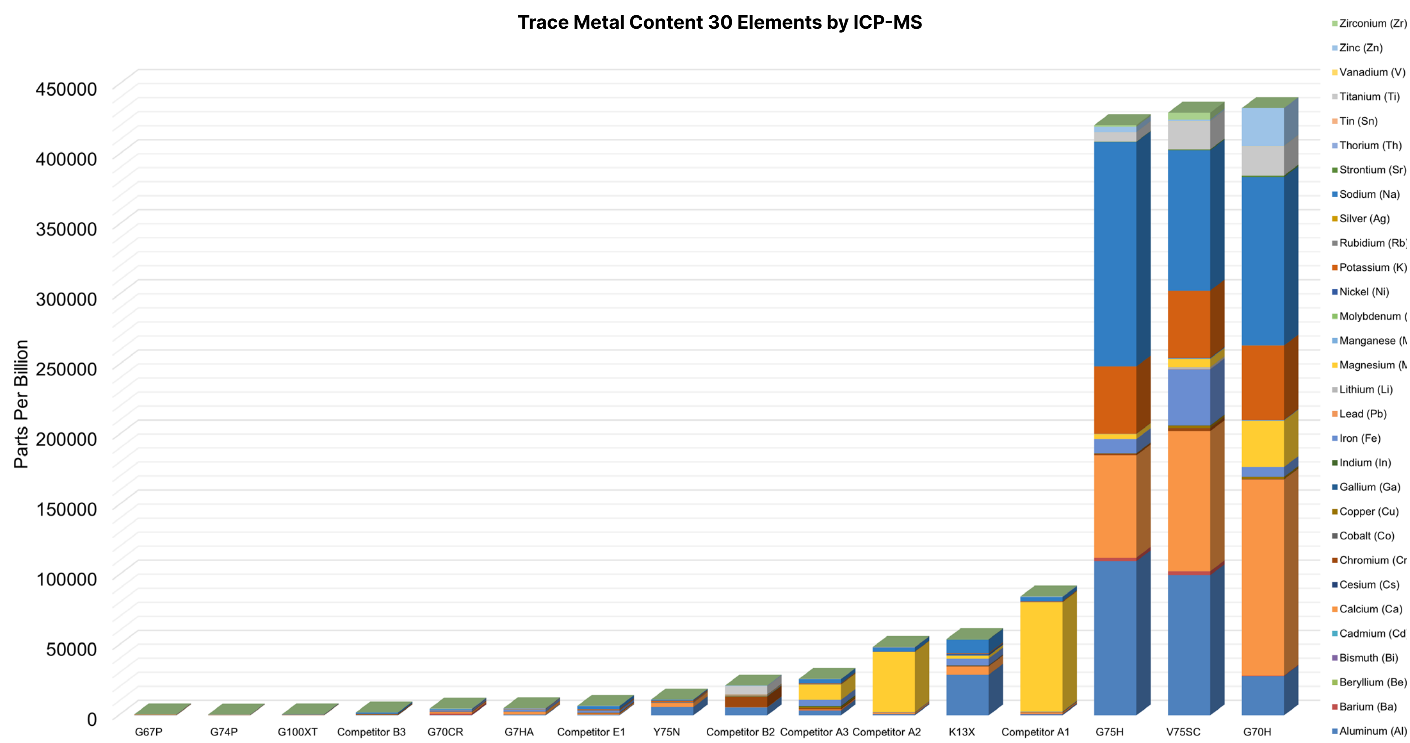


Figure 1. Comparative VPD ICPMS testing of elastomer materials

Precision Polymer Engineering

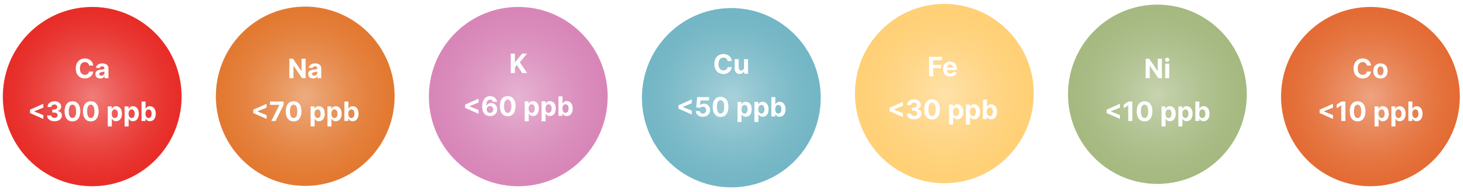


Figure 2. G67P trace metal content

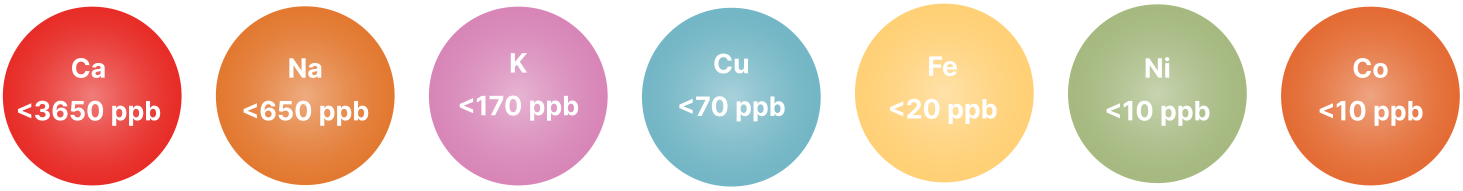


Figure 3. G100XT trace metal content

The materials analysed include the leading elastomer brands and the results are graphically represented in Figure 1. It should be particularly noted that in order to accommodate all the samples tested, a log scale was used. The results show that the elastomers that achieved the lowest trace metal content of all materials tested were entirely organic perfluoroelastomers or FFKMs with two Perlast® grades having the lowest levels and G67P in particular showing a factor 7 improvement over the next best grade. The cleanest fluoroelastomer or FKM material was found to be Nanofluor Y75N, again a fully organic highly fluorinated elastomer. Figures 2. and 3. above illustrate the individual levels for several of the key contaminants that should be avoided for two of the cleanest materials tested.

Conclusion

During wafer processing, the inevitability of elastomer or seal wear in key tool locations during normal operation will expose the wafer to the degradation byproducts of the elastomer material, and therefore also the impurities contained within the elastomer. It becomes clear therefore, that the lifetime is not the only factor that should be considered when making elastomer choices for specific applications. FFKM elastomers are particularly suited to the most critical applications, and the harsh environments presented by higher temperatures, aggressive wet chemical and plasma processes.

The more aggressive the environment and the more sensitive the device, the greater is the need to consider the degradation byproducts of the system components. Use of high purity components becomes a preventative measure, guarding against costly transistor damage or increased risk of poor reliability.

Contamination ultimately results in loss of yield, increased cost, or loss of reputation. Elastomer material that contain only ultra-low levels of metallic contaminants are ideal for manufacturers of devices at advanced technology nodes and include all fabs wishing to minimise the risk of random changes to electrical characteristics and reliability failures.

References

1. "Semiconductor Device Reliability Failure Modes" Richard Blish, Noel Durrant May 2000

2. "Gettering and Transport of Mobile Ion Contamination" Daniel M. Dobkin, http://www.enigmatic-consulting.com/semiconductor_processing/selected_shorts/Gettering.html

3. "Contamination Monitoring" Semilab https://www.semilab.hu/applications/si/contamination-monitoring

4. "The Future of Moore's Law" Ed Sperling Semiconductor Engineering June 2015 http://semiengineering.com/the-future-ofmoores-law/

5. "New Contamination Monitoring Applications Available with Automated VPD ICPMS" Balazs nanoanalysis Analytical Insight, Summer 2009

Global Headquarters
Precision Polymer Engineering
Greenbank Road
Blackburn
BB1 3EA
England

+44 (0)1254 295 400
prepol.sales@idexcorp.com

Americas
Precision Polymer Engineering LLC
PPE, Brenham, USA
3201 S. Blue Bell Road
Brenham TX 77833 USA

+1 979 353 7350
prepol.sales-usa@idexcorp.com

Precision Polymer Engineering is a Unit of IDEX Corporation

Disclaimer
The content provided in this technical paper is intended solely for general information purposes, and is provided with the understanding that the authors and publishers have taken reasonable care and attention. This information is to the best of our knowledge accurate and reliable. However, it is possible that some information in this technical paper is incomplete, incorrect, or not applicable to particular circumstances or conditions. Any use of this information should be done only in consultation with a qualified and licensed professional who can provide specific advice based on a given application, taking into account all relevant factors and desired outcomes. We do not accept liability for direct or indirect losses resulting from using, relying or acting upon information in this technical paper.