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EQUIPMENT FRONTIERS

New torque suppressor cures problems of metal face seal fittings

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The metal face seal fitting is the standard reusable coupler for fluid systems in semiconductor manufacturing facilities. Historically, this fitting has connected lines and components carrying semiconductor gases and liquids throughout the fab and within process equipment. Elaborate and costly strategies have been used to hide fundamental flaws of this fitting: bolting down components, clamps to prevent tube rotation, devices to lock the male and female nut together to prevent loosening, and gas manifolds with additional right angle bends to isolate sections from rotation. Even with all these precautions, technicians inevitably introduce torque in the lines, damage the toroid on each make up, generate particles, and are limited to a 1/8th-turn-past-finger-tight installation regimen.

This study identifies the standard metal face seal fitting as a source of particles in the range of 0.1 to 1.0 microns. Standard fittings are also prone to anomalous loosening and leakage. The OmniSafe fitting, described here, prevents these possibly catastrophic failures.

How face seal fittings work

In the standard metal face seal fitting, components are assembled as shown in Fig 1a. The male and female nuts are threaded together finger-tight, then engaged a further 1/8th of a turn using wrenches. Pressure and rotational torque are transmitted from the inside of the female nut to the back of its gland. Simultaneously, the front of the male nut exerts equal pressure and rotational torque in the opposite direction (Fig 1b). As a result, the two glands grind into the gasket in equal and opposite directions, galling both surfaces and generating particles. The lines twist, and residual torque is stored in the system.

The modified fitting is assembled with standard nuts and modified glands (Figure 1c). Opposing torque suppressors are placed between each nut and its corresponding gland. The torque suppressors engage while the fitting is brought to finger-tight. As wrenches tighten the fitting 1/8th of a turn, pressure and opposing rotational forces are transmitted from the male and female nuts to the torque suppressors. The tongs of each torque suppressor prevent counter-rotation of the other. The resulting purely linear engagement completely eliminates the counterrotational component of the force transmitted to the glands. This fitting generates no residual torque.

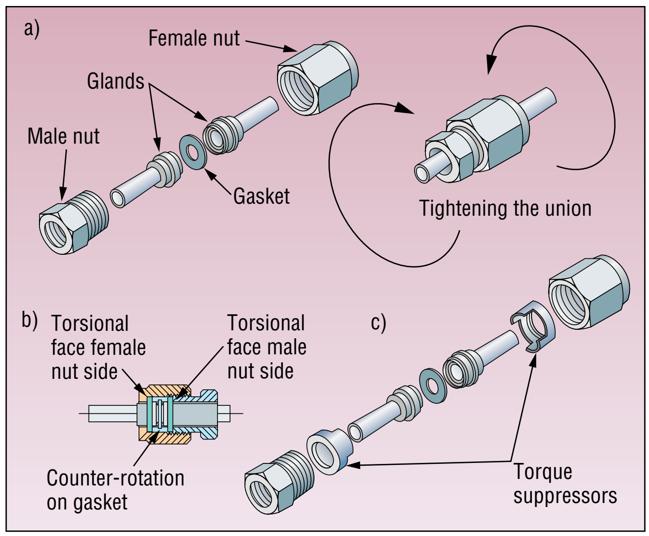

Figure 1. a) Standard metal face seal fitting; b) load transmission diagram; c) modified face seal fitting.

For this study we followed the standard fitting manufacturer's recommendation of tightening only 1/8 turn past finger-tight. Technicians in the semiconductor industry, however, are routinely trained to tighten a fitting 1/4 turn and beyond in order to pass leak checking. Accordingly, the particle generation and galling data shown here are a "best case" scenario. The torque-suppressed fitting may be tightened 1/4 turn past finger-tight with no negative consequences.

Sealing surface damage

The most obvious negative characteristic of a nontorque-suppressed metal face seal fitting is rotational displacement of glands when the fitting is tightened (Fig. 2). This misalignment increases the time and expense of system installation, since technicians

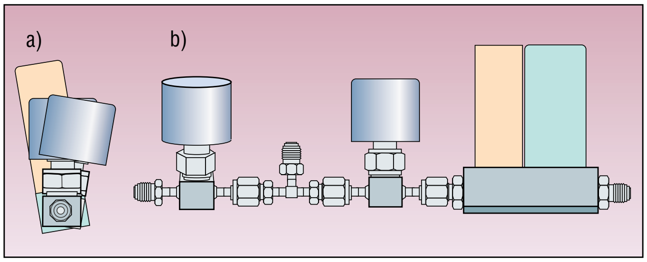

Figure 2. Component rotation using standard fittings without torque suppression, a) end view; and b) side view.

must hold all adjacent components stationary while tightening a fitting. Even more important, in UHP systems, rotational displacement of components causes galling of the sealing surfaces and particle generation.

Semiconductor manufacturing equipment places great emphasis on smoothness and composition of wetted surfaces [1]. These factors are critical to purge- and pump-down times for sequences of semiconductor compounds and to the equipment's resistance to chemical corrosion [2]. After only one make up, the highly polished sealing surfaces in a standard metal face seal fitting have been galled and their ability to seal compromised (Fig. 3a). In the corresponding torque-suppressed fitting, no galling or particles appear (Fig. 3b).

The difference between the sealing surfaces of torque-suppressed and nontorque-suppressed glands becomes more pronounced after multiple make ups (Fig. 3c and 3d). Photomicrographs from multiple make-up studies show that the toroid is increasingly abraded from rotational galling over its lifetime, reducing the glands' ability to make a sharp impression into the gasket at the seal location. In a UHV system, these conditions may lead to a leak or create a contamination entrapment area known as a "virtual leak."

A laser particle counter with 0.1-µm resolution showed that particles in the 0.1- to 1.0-µm size range were produced during make up of a standard fitting, while no particles were produced by the torque-suppressed fitting (Fig. 4). Energy dispersive spectroscopic analysis gives us a quantitative measure of the amount of nickel ground from the gasket into the surface of the gland's toroid. For the standard fitting, the width of the galled zone on the toroid grows with each successive make up. This cumulative damage ultimately affects sealing integrity. EDS of the modified fitting showed no changes in nickel absorption.

Significant linear compression forces are needed to create a seal in a high pressure metal face seal union. Damage to glands and particle generation occur only when rotational forces are allowed to grind the components into each other. Torque suppression can eliminate these rotational forces and their negative effects.

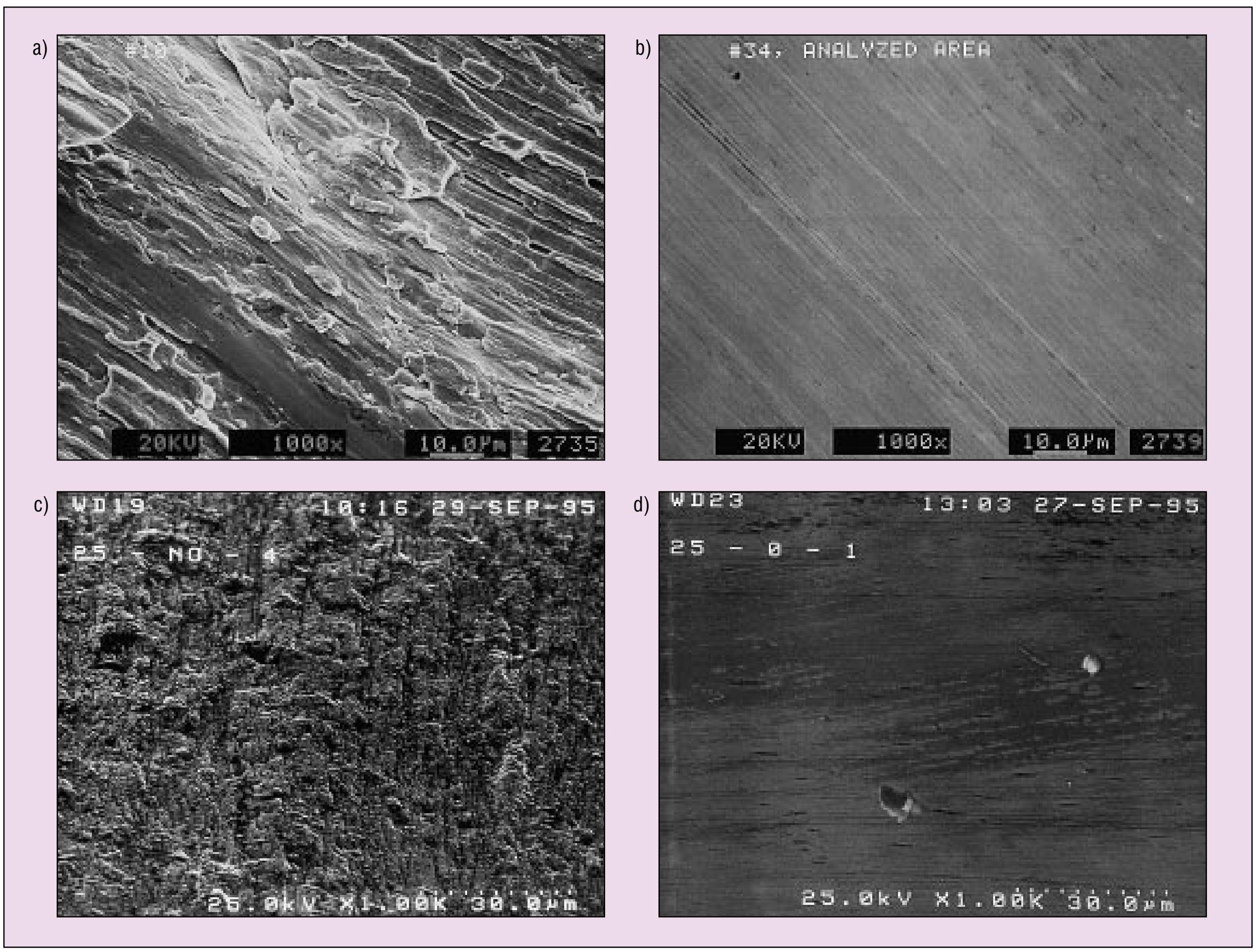

Figure 3. Sealing surfaces of a) standard fitting gland after single make up 1/8th turn past finger-tight; b) modified fitting gland after single make up 1/8th turn past finger-tight; c) standard fitting gland after 25 make ups 1/8th turn past finger-tight; and d) modified fitting gland after 25 make ups 1/8th turn past finger-tight. All four fittings used nickel gaskets.

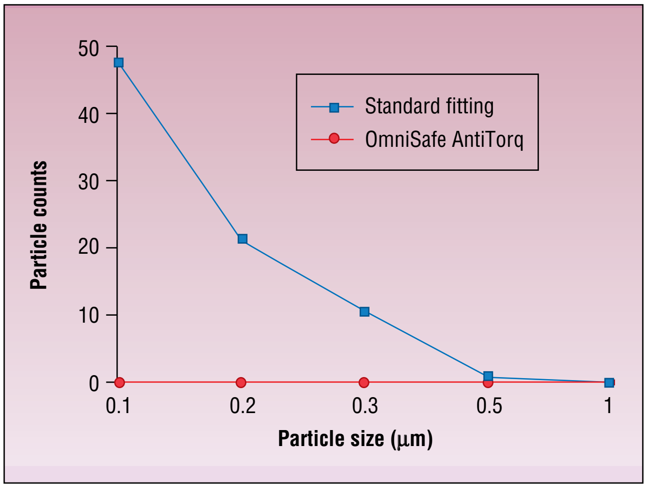

Figure 4. Laser particle counter data comparing standard with OmniSafe fitting. Single make up, five sample average.

Seal loosening

A standard metal face seal fitting may loosen in three ways:

- Rotational torque placed on a component attached to the union
- Vibrational loosening
- Thermal loosening

The first type of loosening, also known as "cross torquing," occurs as torque is applied to an attached component. As the adjacent fitting is tightened, the glands rotate and the male and female nuts experience differential torque. For a fitting that has been made up 1/8th turn past finger-tight, a "break loose" phenomenon occurs at about 55 in.-lbs of torque. This sudden leak is a catastrophic failure if it occurs on a line containing toxic, corrosive, or pyrophoric materials. Torque suppressors eliminate differential torque and prevent this type of loosening. The torque suppressors also "bottom out" on each other in a "safety stop" state if the gasket is sheared or missing, preventing bead-to-bead contact and subsequent gland destruction.

Some attempts to prevent rotational galling in metal face seal fittings have added thrust bearings or a thrust washer inside the female nut to reduce the friction between the female nut and its gland. Since friction between nuts and glands is what holds the fitting together, friction reduction introduces a second liability, vibrational loosening.

Vibrational loosening of a metal face seal fitting may occur in shipping or during operation in the fab. Susceptibility to vibrational loosening is directly related to the break torque of a fitting. A fitting that suppresses torque by reducing friction is more susceptible to vibrational loosening.

The third type of loosening occurs when a fitting with "residual torque" is heated. Residual torque is stored in a fitting as glands of fixed components are counter-rotated by the nuts during tightening. If the nuts are heated, differential thermal expansion of the nuts and melting of the wax coating on the silver-plated threads can release this preload and loosen the fitting. Torque suppressors do not allow the transfer of torque and thereby prevent this type of failure.

Conclusion

Glands of fittings without torque suppression are progressively galled over their life. Galled sealing beads are a source of particles, and may compromise seal integrity. Particles of the size produced during the make up of standard metal face seal fittings will affect yields on 64- and 256-MBit DRAM products [3]. Standard metal-face seal fittings are also susceptible to anomalous loosening; resistance to this loosening is critical, due to the toxic, corrosive, and pyrophoric properties of common gases. The torque suppression fitting tested has no tendency to loosen in any of the scenarios described.

The metal face seal fitting is the high-purity connector of choice for the entire range of high-pressure to high-vacuum applications. Purity and safety requirements pushed the industry to transition from ferruled to face seal fittings in the 1980s and from polymer to metal gaskets in the early 1990s. In the same manner, fittings with effective torque suppression will be required to reach the performance and safety levels demanded by the next generation of semiconductor products. ■

Acknowledgments

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