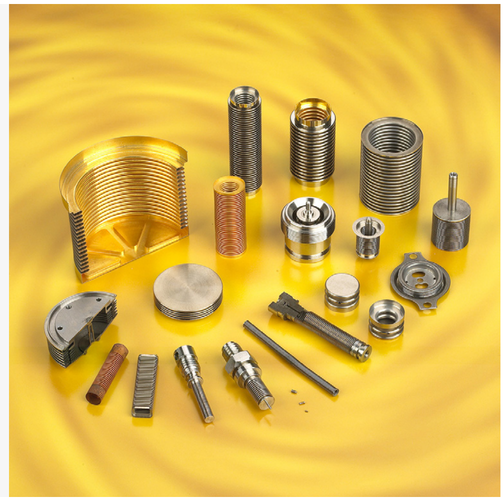
White Paper

MW Components

Six Key Design Features: Metal Bellows for Semiconductor and Ultra-High Vacuum Applications

Highly exacting manufacturing techniques and design tolerances are needed to meet the demanding performance specifications for these applications



The Challenging Relationship Between Bellows, Semiconductor and UHV Applications

Within many of the machine components and assemblies used during the production of semiconductor chips, metal bellows play an essential role to control pressure, vacuum or motion, to position light in a repeatable way, and to help control atmospheres inside the cleanrooms and other pristine environments that are used during the manufacture of these products.

In general, the design and manufacture of metal bellows for use within semiconductor production environments are challenged by a variety of demanding attributes ranging from the need for extremely small dimensions and highly exacting performance specifications, to the potential for exposure to corrosive conditions or media (gases and/or liquids) and the extremely low tolerance to withstand contamination.

Form and Function

A metal bellows typically has the physical form of a flexible, spring-like accordion, but once it is filled with a liquid or gas under atmospheric or vacuum conditions and its ends are sealed, the bellows will be extremely sensitive to a variety of forces, providing a predictable, repeatable, dynamic response within a given machine component or assembly.

Within the realm of semiconductor wafer processing, or UHV or ultra-high-purity processing, vacuum and pressure bellows carry out a variety of functions.

For example, they can:

- Be used in the cleanrooms operated by semiconductor manufacturers to establish and maintain certain atmospheres
- Function within optical devices, to precisely position the filters and lenses that are used to direct light during the production of layered semiconductor components
- Be used to position and mark semiconductor wafers during the cutting of individual chips
- Be used as a flexible, hermetically sealed feedthrough in process chambers to allow the operator to maintain high-pressure or high- vacuum conditions and still manipulate, position and actuate various apparatus used within these process chambers during the manufacture of the final semiconductor chips. Such apparatus include wafer stages, wafer holders and lifters, analytical probes, valves, and actuators.

Optimum Metal Bellows Design Characteristics

Specific aspects of the processing environments that are typically used during semiconductor manufacturing and related ultra-high vacuum (UHV) process applications create distinct challenges during the design and manufacture of metal bellows. Specifically, such bellows must typically be engineered with miniature dimensions (in terms of length, diameter and wall thickness); as well as highly exacting performance specifications related to, for instance, very high reliability and long service life. In addition they must be engineered with very low spring rates (a measure of how many pounds of force are needed to compress the bellows); and maximum leak tightness (to ensure that absolutely no fluid or gas will leak out of the sealed bellows into the surrounding machine assembly, and no fluid or gas from the surrounding environment will leak into the sealed bellows). In these demanding applications, there is typically very low tolerance for any deviation beyond the desired engineering performance envelope.

Similarly, due to the demanding nature of most semiconductor - processing environments, the metal bellows designed for use there must be fabricated from materials that are compatible with the process environment they will encounter. For example, in some semiconductor applications, the bellows must be manufactured from a non-magnetic material; in others, the existence of corrosive process gases impose strict material requirements or constraints.

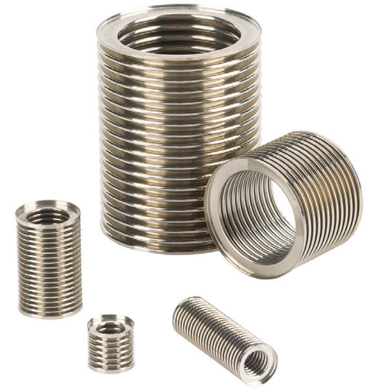
Manufacturing Options

In general, metal bellows are produced using one of three main techniques - electrodeposition (also called electroforming), edge welding and hydroforming. Each technique has its advantages and disadvantages. Among the manufacturing methods available, two - electrodeposition and edge welding - are widely used to produce the bellows needed for semiconductor and UHV applications.

Electrodeposited (also called electroformed) bellows

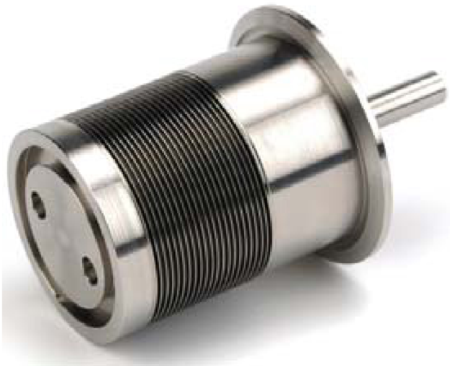
Electrodeposited bellows are produced by plating metal (most often copper, nickel or a nickel alloy) onto a bellows-shaped form (mandrel), and then removing the mandrel using chemical or physical methods. This technique allows manufacturers to carefully control the bellows wall thickness, and to produce bellows with the smallest possible diameters and the thinnest possible walls (on the order of 1/1000 to 1/10,000 of an inch). At these dimensions, the resulting miniature bellows are extremely sensitive and well-suited for precision instrument applications, and can provide very large deflections in response to the application of very small forces (as small as 4 grams).

In some instances, if electrodeposited nickel alone is not an option (due, for instance, to issues that could arise from exposure to corrosive agents), then gold or Parylene-C could be considered for use as a surface coating. Similarly, the semiconductor related machine assembly may require a non-magnetic bellows, then electrodeposited nickel, being ferro-magnetic, will be ruled out, and an alternative such as copper may be considered. In highly specialized cases, nickel may be ruled out in favor of copper (for instance, when the semiconductor also functions as a heat sink - to pull heat away from other components, or to cool or transfer heat - using all copper and no nickel).



A key advantage of electrodeposition is the ability to produce bellows that have highly sophisticated parameters. An electrodeposited bellows can have miniaturized overall dimensions, as small as, 0.020 inches diameter and exceedingly thin wall thicknesses, for instance, down to 0.0003 inches. They can also have an extremely high cycle life and extremely low leak rate (down to 1x10-9 std. cc He/sec, as verified by mass spectrometer - a leak rate that translates to 1 cubic centimeter in 32 years). Plus, they can have a compression stroke, in some special cases, up to 60% of their free length, and can provide relatively large deflections in response to very minute forces - as small as 4 grams.

This combination of attributes makes electrodeposited bellows ideal for extremely sensitive, precision instrument applications. Similarly, electrode- posited bellows are seamless and non-porous - additional attributes that are important in semiconductor-related applications, where minimizing the potential for contamination is a key consideration.



Edge Welded Bellows

By comparison, edge welded bellows can be made from more than a dozen materials including stain- less steel, Inconel, Hastelloy®, titanium and others. They are produced by welding metal diaphragms that have been stamped from strip material, using plasma, laser, arc or electron-beam (e-beam) welding methods. Compared to electrodeposited bellows, this fabrication technique allows for the production of stronger, more robust bellows. However, this fabrication is not able to produce bellows with extremely small diameters or thin walls.

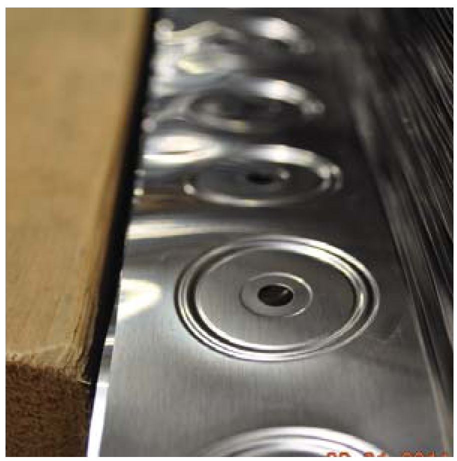
Compared with those produced using the other fabrication methods, edge welded bellows have the highest stroke length (reaching 90% of their free length) and enjoy excellent compression capabilities, allowing for increased expansion and contraction during operation. And with a greater variety of metallurgical options available, edge welded metal bellows can also withstand exposures to extremes in terms of liquid and gas media and temperatures depending on the materials.

The important design and manufacturing considerations discussed below are essential to maximize the functionality of metal bellows and increase their compatibility in semiconductor and UHV applications.

Six Key Design Considerations

1. Compatibility issues will dictate metal selection.

In many semiconductor-production processes the presence of corrosive gases creates specific requirements or constraints as to which metal may be considered for the engineered bellows being used in the process. While the final specification will be dictated by site-specific criteria, the list of acceptable materials for electrodeposited bellows typically includes nickel, copper, and gold in any combination. For edge-welded bellows, additional materials include AM 350, types 316L, 304L and 347 stainless steel, Inconel 718/625, Hastelloy 276C, Haynes 242, and Titanium grades 1–4 (ASTM-B265).



2. Electron beam welding can be used to eliminate the use of solders and epoxies.

In many industrial applications, solders and epoxies are used to connect the metal bellows within the machine assembly. However, both of these tend to produce potential contaminants (via off-gassing) that cannot be tolerated within pristine semiconductor-manufacturing environments. As a result, such applications tend to require welded connections to join the bellows into the machine assembly.

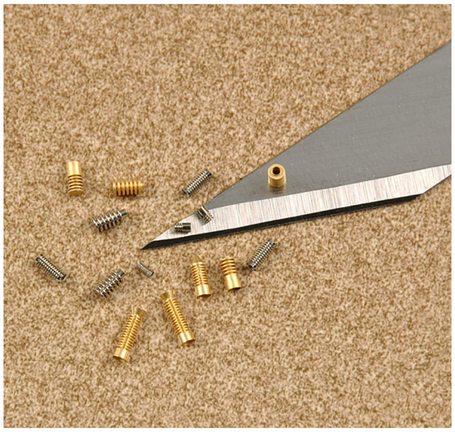
While laser welding is a desirable and widely used option for connecting engineered bellows to the machine assembly in many applications, bellows made from electrodeposited nickel cannot be laser welded directly to steel parts within the machine assembly. To expand the versatility of electrodeposited nickel bellows, a small transition piece of 304L and 316L stainless steel can be welded to the bellows using electron beam (e-beam) welding, and then that steel transition piece can be laser welded to steel parts within the machine assembly. Electron beam welding is carried out with using highly automated computer controls, and this welding technique imparts only localized energy to the work piece, thereby minimizing distortion of thin parts. It also produces exceptionally clean welds in applications that cannot tolerate contamination or volatile outgassing. Such a workaround solution would require that sufficient space is available within the space in which the bellows assembly must fit, or would require special design considerations at the time the bellows is ordered.

3. Proper manufacturing can ensure tight spring rate tolerances and minimal stroke.

Metal bellows used in many semiconductor applications must meet very exacting design tolerances. With proper manufacturing, bellows can be produced with walls as thin as 0.0003 inches and spring rates can be controlled to +/-10%. In some applications gold flash (0.00005-inches, ASTM B 488) can be applied over these ultrathin bellows walls to further improve leak tightness and corrosion resistance.

4. Stringent cleaning protocols required by the semiconductor process have a direct impact on the bellows manufacturing technique and/or the material.

Most machine assemblies used in semiconductor manufacturing set forth stringent cleaning protocols. Many require ultrasonic cleaning in a fluid medium for any components that go into the semiconductor equipment During bellows specification, the OEM must share specific cleaning specifications in advance, as they will directly impact which manufacturing technique and which materials may be considered for the required bellows. For instance, electrodeposited bellows can be cleaned using ultrasonic methods - but only as long as the ultrasonic frequency does not exceed 40 kHz otherwise the bellows will be damaged above the critical threshold level. It is important for OEMs and the bellows manufacturer to work closely together during the initial specification.



5. Small size requirements are critical.

As the demand for miniature manufacturing increases, the device geometry continues to shrink, and this creates ongoing challenges in terms of the tight space constraints that engineered bellows must meet. Today's advanced electrodeposited technology allows metal bellows to be manufactured in sizes ranging from 0.020 inches to 12 inches diameter.

6. Edge welding can produce bellows for semiconductor applications in a range of metals and dimensions.

Today's advanced edge welding techniques allow bellows to be produced in diameters rang- ing from 0.396 inches to 36 inches and a range of metals including: Inconel, Hastelloy®, AM350, titanium or stainless steel for semiconductor applications. In some instances such as UHV applications - stainless steel is the only material option. However, edge welded bellows face some size limitations. Again, careful collaboration between the OEM and the design ngineer is critical to determining the best manufacturing technology.

Conclusion

Thanks to today's advanced manufacturing technologies, miniature, robust metal bellows can be reliably manufactured to meet the highly exacting needs of machine components and processes that are used in semiconductor manufacturing and UHV processes. The most appropriate manufacturing technique (for instance, electrodeposition versus edge welding), and the most appropriate materials will be determined by the specific requirements and constraints of the process in terms of critical dimensions, material compatibility with the process environment, cleaning requirements, and more. The ability to clearly articulate all of these key attributes in the bellows specifications will ensure success.