Leak Testing Process Gas Components and Systems for Semiconductor Manufacturing

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Introduction

Manufacturing integrated circuits involves many complex process steps that require the use of high-purity gases under vacuum conditions in process chambers. For example, semiconductor-processing applications such as microlithography, low-pressure chemical vapor deposition (LPCVD), ion beam etching, sputtering, ion beam implantation, and molecular beam epitaxy all require high vacuum maintenance. Likewise, distribution systems that deliver gases such as carbon tetrachloride, trichlorofluoromethan, methylene fluoride, etc. must be tightly sealed in order to prevent emissions and maintain gas purity.

Helium leak detection today has become the method of choice for testing process gas components and systems. The beauty of helium is that the molecule is so small that it quickly permeates the tiniest leaks. Helium is also present at levels of only 5 parts per million (ppm) in the ambient air. These properties result in a sensitivity that ranges up to seven orders of magnitude greater than conventional bubble testing methods. Finally, helium is nontoxic and nonexplosive.

Leak Integrity Requirements

In establishing leak integrity requirements it's important to remember that everything leaks. Establishing leak integrity requirements at a higher level than necessary will add time and cost to the leak testing procedures. Leak integrity is typically specified in terms of cc/sec at atmospheric pressure. A leak integrity rating of 10^{-1} atm.cc/sec indicates a leakage of 6 cc per minute. On the other hand, a rating of 10^{-11} atm.cc/sec implies a leakage of only 0.03 cc per century. Helium leak detectors can detect leaks up to 10^{-9} atm.cc/sec while bubble testing can detect leaks down to 10^{-3} atm.cc/sec and halogen sniffers can go down to 10^{-5} cc/sec.

Examples of leak integrity requirements for the industry are as follows:

- A 1 standard cubic centimeter per minute (sccm) gas flow line under a partial vacuum must contain less than 1 part per million (ppm) air impurity from leaks. Since 1 sccm equates to 0.0167 std cc/sec, and the maximum tolerable air leak in the gas flow system is one millionth of this, the helium leak tightness requirement equates to about 4 x 10^{-8} atm cc/sec.

- For pressurized gas lines, one can consider an example of potential outward leaking gas that should typically induce no more than a 1 ppm uniform concentration into 10 liters of surrounding unventilated air in a 24-hour period. 1 ppm in atmosphere is a partial pressure of 7.6 x 10^{-4} Torr. Considering the leak rate of air over a 24-hour period to create this partial pressure in a 10-liter volume, this corresponds to a helium leak rate of about 3 x 10^{-7} atm.cc/sec.

Helium Leak Testing Methods

Leak testing of gas distribution systems typically involves numerous components such as valves, flow controllers, transducers, cylinders, filters, and gas lines that are typically 1.4" (0.6 cm) outside diameter and up to several hundred feet long. Leakage may occur from the inside of the components to the outside or from the outside to within the component by a pressure boundary, while the leak rate will primarily depend on the leak geometry, the type of fluid, temperature, and pressure conditions.

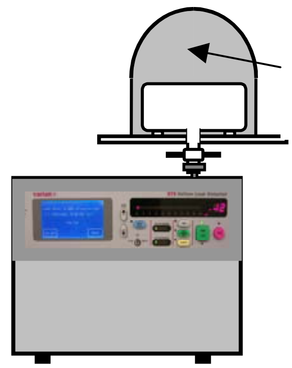


Fig 1

Two basic types of testing are typically available for testing gas delivery systems and their components using helium leak detection technology. Depending on the component to be tested, the application, and the required sensitivity, one or a combination of the following tests can be performed to identify or measure the leaks:

1. Outside-In (See fig #1)

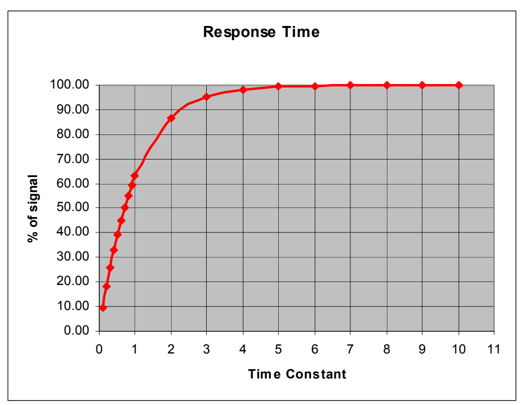
This method is applicable to components that are used under vacuum conditions. In this test arrangement, the helium leak detector is directly connected to the part to be tested, while helium is either sprayed on the exterior of the possible leak sources, or the item under test can be placed in a helium-filled enclosure.

Important Test Considerations for the "Outside-In" method

1. When spraying helium on the exterior it is important to know that the leak value indicated depends on the helium concentration at the leak location.

   Spraying a very small amount of helium from a relatively large distance or for a very short time period might not provide satisfactory results, as helium will not displace the air that was initially surrounding the leak.

2. When a helium gas enters an evacuated system it will lead to an increase in partial pressure over time. At the same time the leak detector will evacuate the part under test, possibly with the aid of an auxiliary vacuum pump. Depending on the part's internal volume and on the total helium pumping speed provided the helium signal would increase over time in an exponential way. This behavior is called "response time" and is defined as the time it takes to reach 63% of the leak value.



$$T_{63} = \frac{V}{S}$$

With:

T = Time in seconds
V = Part volume in liters
S = Helium pumping speed in liters/second

Spraying helium for a very short time period might not provide satisfactory results, as the helium signal might not reach satisfactory levels.

2. Inside-out (See fig #2)

Inside-out leak testing is mainly applicable to components used under pressurized conditions. The inside of the part is filled with helium or a helium/gas mixture to the specified test pressure. The part is placed inside a vacuum-tight fixture, which is evacuated and connected to the leak detector. By utilizing higher helium fill pressure, the effective sensitivity of this test can be improved.

With this method a quantifiable total leak rate can be established, but pinpointing the leak location may not be possible. However, the location of the leak can be established by removing the part from the test chamber and moving a sniffer probe connected to the leak detector over the surface of the pressurized part. It should be noted that the sensitivity is limited to about 10^{-7} atm.cc/sec due to the presence of ambient helium in air. Sniffing capabilities can be improved by sniffing the part in a "neutral" environment such as a glove box purged with nitrogen.

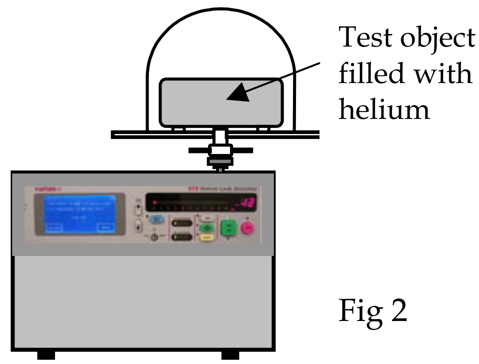


Fig 2

Important Test Considerations for the "Inside-Out" method

1. In order to reduce the cost of helium gas, a gas mixture can be used depending on the sensitivity requirements. Under viscous flow conditions, normally encountered when testing pressurized components such as during a sniffing process, and using a gas mixture, each gas will flow at the same rate regardless of the concentration. Viscous flow involves the flow of gas through a channel under conditions such that the mean free path is very small in comparison with the smallest dimension of a transverse section of the channel. At these pressures the flow characteristics are determined mainly by collisions between the gas molecules.

   Example: When using a 10% helium concentration in a gas mixture (10% helium + 90% nitrogen) the test sensitivity is reduced by a factor 10.

   It is important to know that if a part is not being evacuated before charging a mixture will be created

   Example: Adding 1 bar (Abs) of helium to a part at atmospheric pressure will result in a 50% tracer gas concentration.

2. Another way to conserve helium expenses or to improve test sensitivity is to increase the pressure differential across a leak.

   When the flow through a leak changes proportionally with the squares of pressure differential (normally encountered when testing pressurized components such as during a sniffing process) a leak is considered viscous.

Practical Example:

A vessel of 10,000 liters is to be tested at 1e-05 atm.cc/sec by the sniffing method at 2 bar (Abs). A substantial reduction in helium consumption can be achieved by using a 20% mixture of helium at 4 bar (Abs).

At 2 bar (Abs) with 100 % Helium = 2 bar * 10,000 = **20,000** bar.l

At 4 bar (Abs) with 20 % Helium = 4 bar * 10,000 * 0.2 = **8,000** bar.l

Total savings are calculated to be **12,000** bar.l of helium, which means a significant cost reduction, while the sensitivity setting remains at 1e-5 atm.cc/sec:

When testing pressurized components in a vacuum, the flow through the leak may change proportionally with the pressure. This is considered a molecular leak: the mean free path is much greater than the largest dimension of a transverse section of the channel. The flow characteristics are determined by collisions of the gas molecules with surfaces and flow effects from molecular collisions are insignificant. However, under molecular conditions the helium flow will not be determined by the total pressure, but by the partial pressure of the tracer gas only!

Practical Applications

1. Testing a valve seat

In order to test the sealing capability of a closed off valve or regulator, one end of the part is connected to and evacuated by the leak detector, while the other end, isolated by the closed valve seal, is exposed to the tracer gas.

Notes:

- Due to the different seal designs, a specification for the leak integrity across a closed off flow control valve is typically several orders of magnitude less demanding than for a dedicated shutoff valve.
- If testing procedures require a combination of tests, testing any part previously exposed to helium will likely create a large apparent leak signal due to residual helium. To avoid the requirement for extensive purging then the test that requires evacuating that surface with the leak detector should be done prior to the test that exposes it to helium.

2. Testing a long gas line

In most semiconductor process facilities, the storage location of process gas bottles is remote from the process tools that use the gas. As a result, the lines that carry the gas to the process tools are often several hundreds of feet long. Thus, consideration must be given to the leak integrity and testing methods for these long runs of process gas lines. The response time of helium sprayed at a long tube evacuated by a leak detector can be appreciable.

The net pumping speed to the leak detector from the point of entry determines the signal response time for small leaks under molecular flow conditions at the leak site as indicated before.

Example:

If a tube with an inside diameter of 0.2" (0.5 cm) is held under molecular flow conditions then a 10-meter length has a calculated conductance of only 0.0015 liters per second. If the volume to be considered is that of the tube itself (0.2 liter), then the time constant is about 130 seconds for a leak entering at the far end of the tube. Alternatively, if the tube is held under viscous flow by bleeding nitrogen in at the far end of the line creating a pressure of 1 Torr, the conductance is calculated to be 0.011 liters per second. This will result in a corresponding theoretical time constant of about 20 seconds. Note that a change in pressure differential across the leak affects the outflow so the sensitivity settings need to be adjusted accordingly.

It is obvious that the higher pressure is beneficial for leak testing since it helps sweep the helium from the point of leakage downstream to the leak detector itself. Using nitrogen as a purge gas will also help to remove the ambient air, enhancing the sensitivity capabilities of the test procedure. It is however advisable to install a calibrated leak (representing the required sensitivity setting) at the far end of the tube as well to determine the overall system sensitivity capabilities.

In gas flow systems that contain an array of components such as shutoff valves, flow controllers, transducers, and particulate filters, the effective flow conductance to the leak detector may be dramatically lower than an open tube. Thus, longer leak response times may be required, which can be empirically measured by using a calibrated helium leak at the far end of the line.

Leak testing is usually performed in the same direction that a leak is expected to occur. This is important because pressurizing and pulling a vacuum in a cavity stresses seals differently. But if the testing pressures are less than the actual process gas pressures, then a higher sensitivity test is required as outlined under test considerations for the outside-in method. In the case of testing gas lines with metal seals, the inside-out method can be effectively used to improve the leak testing process and capabilities.

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