Selection and Application Criteria for Magnetic-Liquid-Sealed Vacuum Rotary Feedthroughs

By Hiro Sugiyama, Hiroshi Matsuura, and Yutaka Suzuki, Rigaku/USA, Danvers, Mass. and Rigaku Corp., Tokyo, Japan

Clean, reliable sealing of rotary motion feedthroughs in vacuum processing systems has been a perennial problem in wafer fabrication and other vacuum dependent applications. Atmospheric leakage or particulate generation can eitherstop a process or ruin a load of wafers. Numerous techniques have been tried over the years to solve this problem.

Rotary Seal History

For many applications, a simple arrangement of O-rings around the rotating shaft has been used successfully. This design has the advantage of simplicity, and it is inexpensive. The disadvantages are, of course, that in time the O-ring wears and needs to be replaced. Unless a thorough preventive maintenance program is instituted and adhered to, these feedthroughs could fail during processing, thereby leading to costly downtime and product loss. The other disadvantage of the O-ring feedthrough configuration is that it sheds particulates of the seal material, which in turn can cause contamination.

For some low and rough vacuum processes, a labyrinth seal is used. The labyrinth seal uses a series of grooves and gaps of small dimensions between the rotating shaft and its housing to diminish, but not stop, the inflow of atmospheric air. This type of seal is typically found in "dirty" processes outside the semiconductor industry.

In certain ultrahigh vacuum (UHV) applications, a magnetic feedthrough is used. This type of feedthrough employs a magnet on the atmosphere side of the shaft to convey the motion through a thin metal sealing disk to another magnet on the vacuum shaft. Since the coupling of one magnet to the other through the disk is not very strong, the torque transmitted by this method is somewhat limited.

Each of the preceding techniques has significant drawbacks, whether it be particulate generation, low speed limitations, limited torque transmission, or atmospheric leakage.

Magnetic Liquid Sealed Vacuum Rotary Feedthroughs:

About 15 years ago, magnet-liquid-sealed vacuum rotary feedthroughs came into usage in microelectronic manufacturing processes. The early feedthroughs consisted of a machine-grooved shaft held into a housing by a pair of bearings on either end. The housing also held a simple arrangement of magnet and pole pieces, Figure 1. It is in

> ***By lining up a number of these pole piece and magnet combinations, magnetic liquid seals that are able to withstand almost any pressure differential can be constructed.***

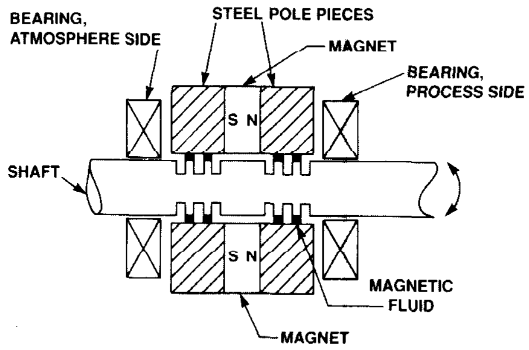

Figure 1. Original design of a rotary vacuum feedthrough.

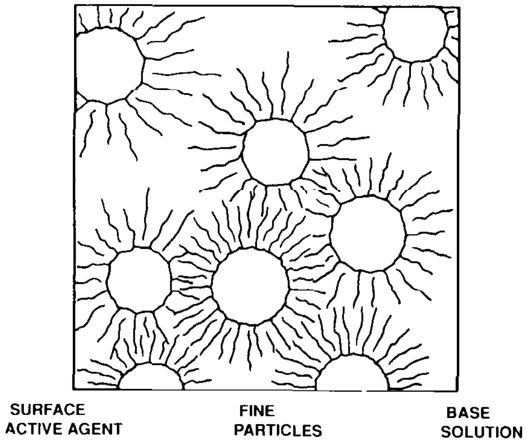

Figure 2. State of magnetic fluid.

Distributed through the courtesy of **Rigaku/USA Corporation**, Danvers, Massachusetts the gap between the pole pieces and the rotating shaft where the magnetic liquid is captured and held, thus forming a liquid "O-ring". This radial gap is typically on the order of a few thousandths of an inch.

This magnetic liquid O-ring is usually capable of withstanding one or two lb/in^2 of differential pressure. When a large number of the liquid seals were lined up, a seal capable of withstanding atmospheric pressure was made.

The magnet liquid generally consists of a base material with a colloidal suspension of extremely small (on the order of 100 Å or 10 nm in diameter) magnetic particles coated with a surfactant agent to prevent clumping from magnetic attraction, Figure 2.

These early feedthroughs were capable of higher rotational speeds and torque transmission than some of the less sophisticated methods discussed. One drawback was that the grooved shaft weakened and snapped if excessive or impulsive loads were applied. The other major drawback was that the early magnetic liquids were composed of high-vapor-pressure base materials and tended to evaporate relatively quickly. This meant the feedthrough had to be periodically removed from the system, rebuilt, and recharged, leading to costly downtime.

Various types of base materials for the magnetic liquid have been tried, including low-vapor-pressure-hydrocarbons and fluorocarbon-based fluids. One of the major problems is the ultra-low vapor pressure materials usually form weak magnetic liquids and need a very strong magnet field to hold the fluid in place. This means that either stronger magnets must be employed or more groove-gap combinations are required, which in turn leads to bulkier and more expensive magnetic liquid seals. There also are intrinsic limitations in the strengths of readily available magnetic materials.

About twelve years ago, an advanced design for magnetic liquid sealed vacuum rotary feedthroughs was introduced[1]. The major distinction between this newer type of feedthrough and earlier commercially available models is the that the feedthrough employs knife-edge grooves only in the pole pieces, thus allowing the magnetic field to be more concentrated and in turn permitting the use

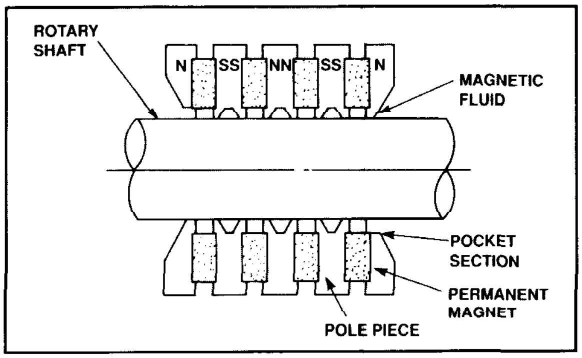

Figure 3. Repulsive magnets and multistage polepiece.

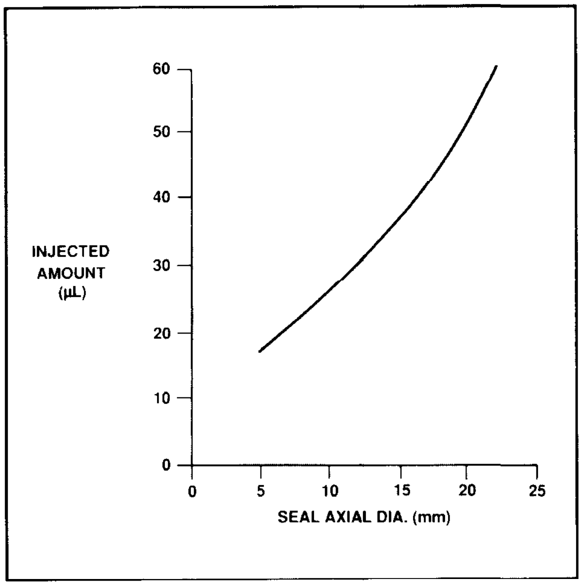

Figure 4. Injected amount of magnetic fluid

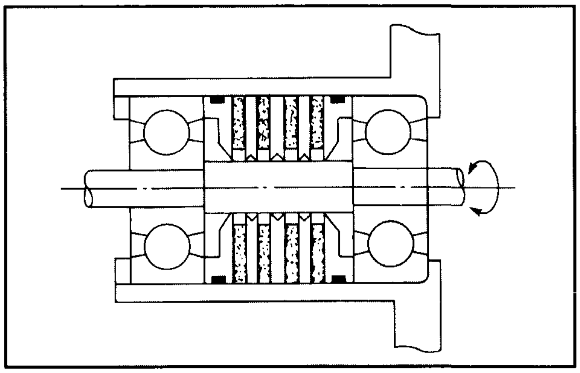

Figure 5. Type where both sides of seal are supported with ball bearings.

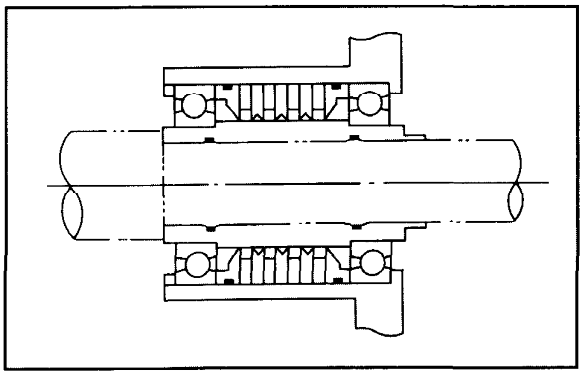

Figure 6. Hollow shaft type

TABLE 1 — SPECIFICATIONS OF MAGNETIC FLUIDS

Type	RMF4230	RMF2012	RMF3020	RMF2050
Saturation magnetization (Gauss)	450	200	300	200
Specific gravity	1.30	1.16	2.15	2.11
Viscosity (CPS at 20°C)	300	120	2000	5000
Vapor pressure (Torr • 20°C)	$6\text{x}10^{-10}$	$6\text{x}10^{-10}$	$2\text{x}10^{-6}$	$2\text{x}10^{-11}$
Vapor pressure (Torr • 100°C)	$2\text{x}10^{-5}$	$2\text{x}10^{-5}$	$5\text{x}10^{-3}$	$5\text{x}10^{-7}$
Base solution	Alkyl naphthalene	Alkyl naphthalene	Perfluoro-polyether	Perfluoro-polyether
Application example	Vacuum seal	Exclusion seal	Low vacuum seal for active gas	High vacuum seal for active gas

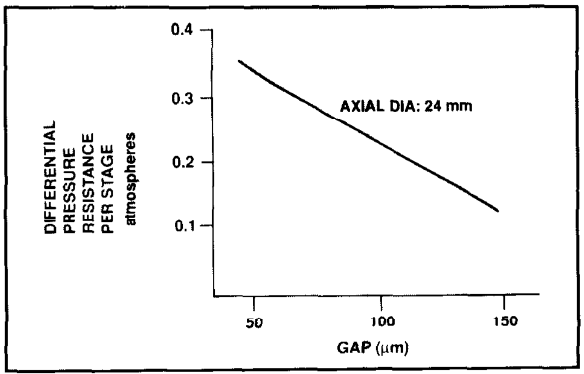

Figure 7. Relations between differential pressure resistance and gap.

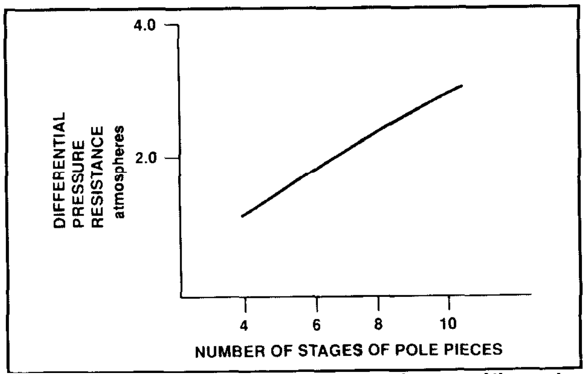

Figure 8. Relation between differential pressure resistance and the number of magnetic stages.

of much lower-vapor-pressure magnetic liquids, Figure 3.

By lining up a number of these pole piece and magnet combinations, magnetic liquid seals that are able to withstand almost any pressure differential can be constructed. The use of lower-vapor-pressure liquids also contributes to extremely low rates of evaporation thus virtually eliminating the possibility of contamination to the process from the feedthrough. Feedthroughs using ultra-low-vapor-pressure materials rarely need to be removed for maintenance, unless they are used in a high temperature environment.

Custom Designs for Specific Applications:

As the use of magnetic-liquid-sealed feedthroughs progressed, the number of applications also increased. Some of these applications required novel and creative solutions to the problem of sealing rotary motion.

For example, *ion implantation* systems generally have a large and heavy platen rotating at high speed, thus requiring the development of large shaft diameter feedthroughs capable of withstanding higher applied torque without flexing and maintaining the proper gap for sealing.

Other applications, working with aggressive atmospheres, such as *chemical vapor deposition* (CVD), required the development of the cantilever feedthrough. In this design, the bearings are both on the atmosphere side fo the feedthrough, followed by the sealing portion on the vacuum, or process, side. Again, precise engineering was required to permit high torque transmission and still prevent flexing of the shaft.

Many process applications operate at higher temperatures and need to be water cooled. For these, the coaxial water cooled feedthrough with a hollow shaft was developed. Water passes through a rotating water fitting, up the shaft, into the process platen, circulates and removes the excess heat. For many high temperature applications the feedthrough itself is also cooled with water.

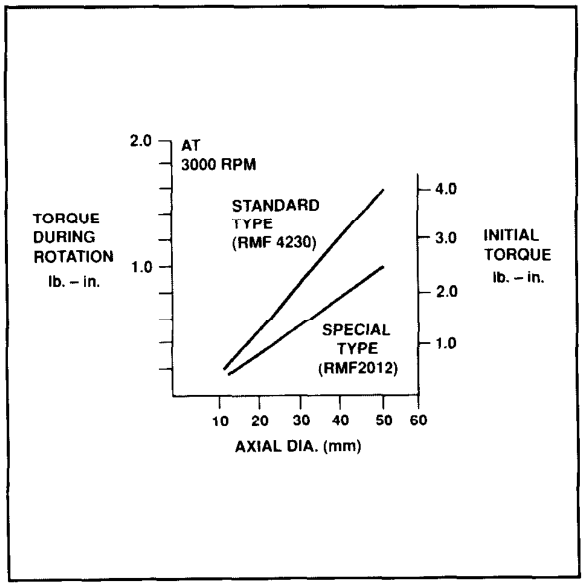

Figure 9. Torque-shaft curve.

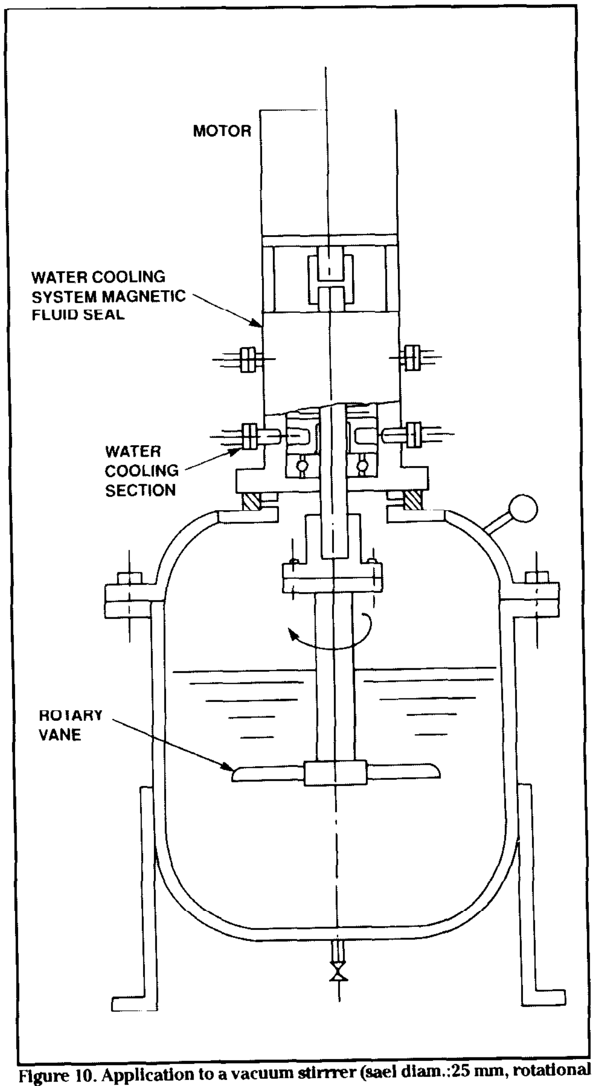

Figure 10. Application to a vacuum stirrer (sael diam.:25 mm, rotational frequency: 10 000 rpm, vacuum: 10^{-6} torr.

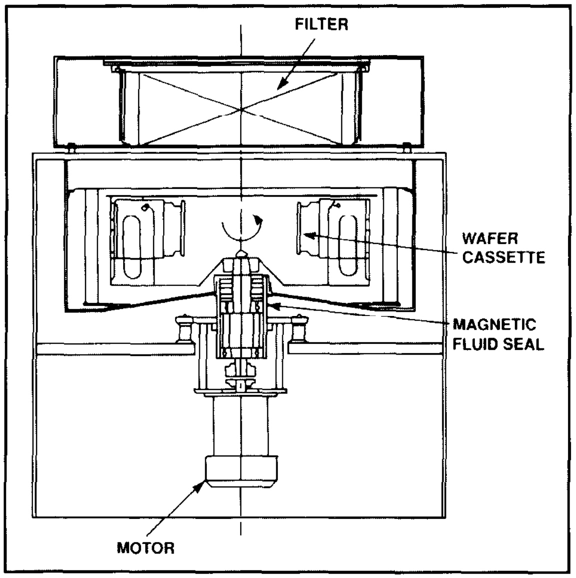

Figure 11. Cross-section of a spin dryer.

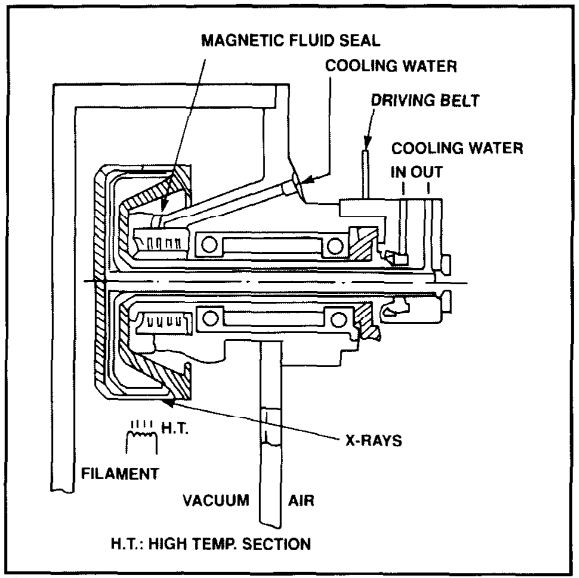

Figure 12. Rotating anode assembly of x-ray generator.

Epitaxial reactors and *CVD* systems, where the process takes place at elevated temperatures, need a feedthrough design capable of delivering a considerable amount of cooling media to the proper places, such as the platen and feedthrough/system interface. In some cases, for very hot applications, a high heat capacity gas, like helium, may be employed for cooling.

Other applications require both rotary and linear motion of the same shaft. For these, a metal bellows and magnetic liquid seal combination is used. One end of the metal bellows is welded to a flange, while the other end is welded to the outer body of the feedthrough. The main flange is then bolted to the processing system.

They are widely employed in ion implantation systems, crystal growing furnaces, a wide variety of both sputter and evaporative deposition equipment, CVD systems, epitaxial reactors, and wafer spin drying equipment...

Some *sputtering* and *evaporative deposition* systems also may need coaxial rotary motion. This special requirement is resolved by using one magnetic-liquid-sealed feedthrough within another magnetic-liquid-sealed feedthrough. For certain operations, the inner feedthrough has a hollow shaft in which the main system shaft is placed.

More complex designs employing combinations of coaxial rotary and linear motion are used in advanced designs for water cooling.

Magnet liquid sealed feedthroughs are now being used in almost every conceivable vacuum and controlled atmosphere processing application. They are widely employed in ion implantation systems, crystal growing furnaces, a wide variety of both sputter and evaporative deposition equipment, CVD systems, epitaxial reactors, and wafer spin drying equipment, to name but a few of the applications within the semiconductor fabrication industry.

Future Trends:

As the requirement for smaller integrated circuit line widths and higher wafer yields increases, the requirement for virtually non-contaminating vacuum components must be met. To minimize contamination it is essential to use ultra low vapor pressure magnetic liquids. These fluids can only be effectively employed when the concentration of magnetic field strength in the feedthrough seal region is sufficient. the Rigaku rotary magnetic liquid sealed feedthrough was specifically designed to meet these needs. **MMT**

Reference

1. Developed by Rigaku Corporation.

For additional information on any aspect of this article, Hiro Sugiyama can be reached at Rigaku/USA, Northwoods Industrial Park, 200 Rosewood Drive, Danvers , Mass.01923 (telephone 508/777-2446), Hiroshi Matsuura and and Yutaka Suzuki can be reached at Rigaku Corporation, 3-9-12 Matsubara-cho, Akishima-shi, Tokyo, Japan 196 (telephone 0425-41-1661).

Reprinted from *Microelectronic Manufacturing and Testing*, October, 1989