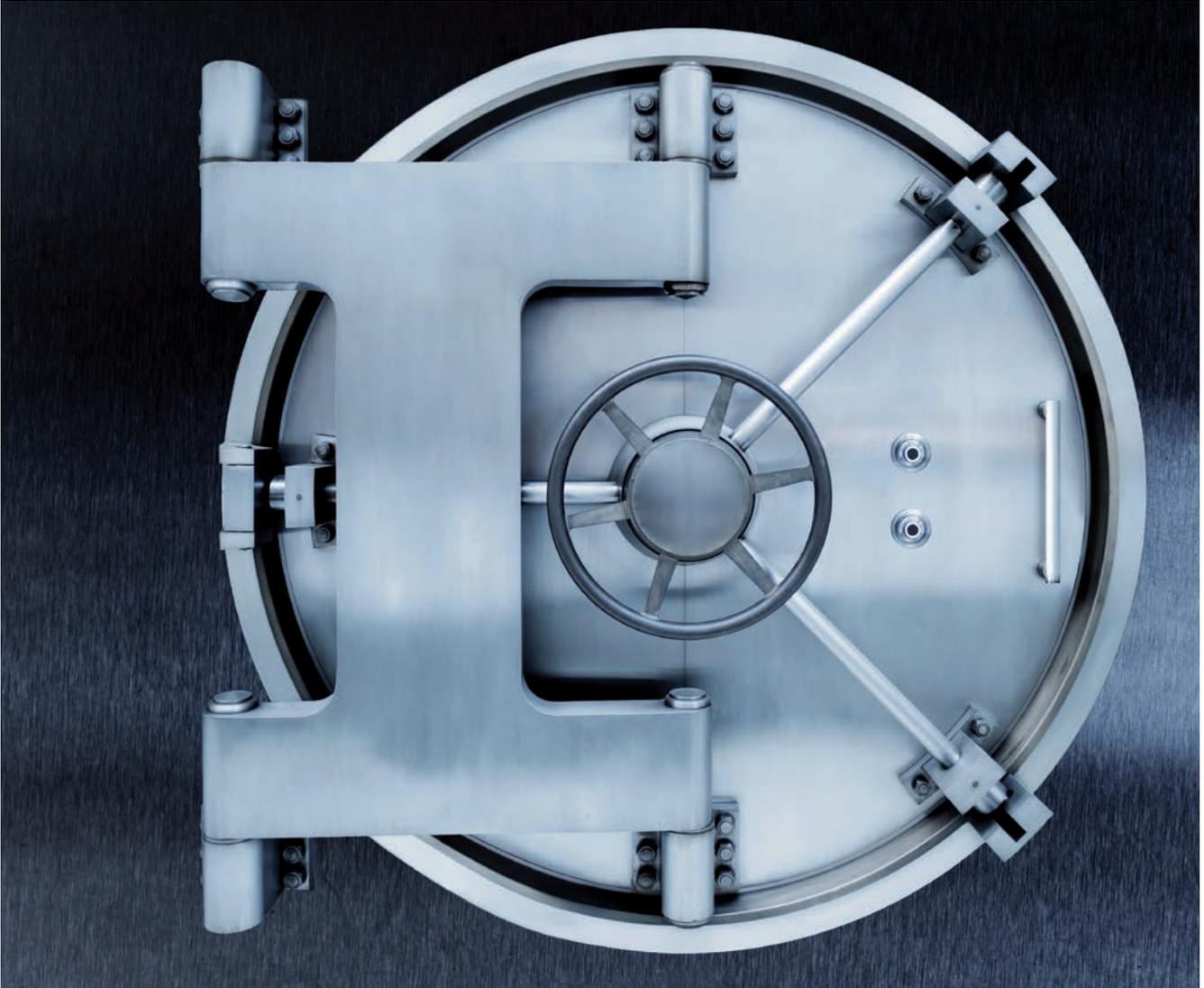




SCHOTT
glass made of ideas

Hermetic Packaging
and Sealing



Content

4	SCHOTT. Glass made of ideas	34	Ceramic-to-Metal Seals
6	Our company: SCHOTT EP	38	Package Closing Technologies
8	Introduction to Hermetic Packaging	40	Materials Data
12	Passivation Glass	42	Quality Assurance
14	Reed Glass and Transponder Glass	44	Competence Centres
18	Glass-to-Metal Seals		

SCHOTT is a leading international technology group in the areas of specialty glass and glass-ceramics. With more than 130 years of outstanding development, materials and technology expertise we offer a broad portfolio of high-quality products and intelligent solutions that contribute to our customers' success.

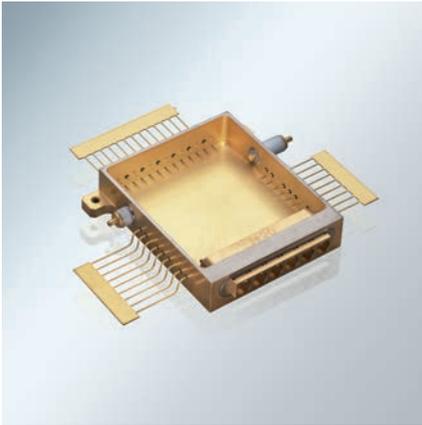
As early as the 1930s, SCHOTT's Business Unit Electronic Packaging developed glasses for the hermetic sealing of glass and metal. Ever since, this technology has been helping to protect sensitive electronic and opto-electronic devices and enabling improvements of innumerable products with respect to their technological functionality, performance, user-friendliness and safety. This handbook shall provide helpful information on hermetic glass-to-metal, ceramics-to-metal and glass encapsulation technologies.



SCHOTT. Glass made of ideas.

This is not just a slogan. It is our business philosophy at SCHOTT, as each product is only as good as the idea behind it.

Above all, it is our customers who provide the impetus for innovation. They expect us to develop products that enable them to turn their ideas into reality. This is why we made it a rule to work with our customers rather than work for them. With this in mind, we have repeatedly managed to set new standards ever since the company was formed in 1884. Guided by our core values of “competence, creativity and customer orientation”, we have become one of the world’s leading glass technology groups, providing components and solutions that enable a wide variety of applications.



Business Unit Electronic Packaging

Hermetic Packaging Know-How since the 1930's

The Electronic Packaging Business emerged from so-called "electronic glass" applications. As early as the 1930s, these glasses were developed for the hermetic sealing of glass and metal. Ever since, we have been developing, manufacturing and optimizing hermetic packaging solutions by using specialized glass, glass-to-metal and today also ceramic-to-metal sealing technology. Our technology has been helping to provide reliable, long-term protection of sensitive electronic and opto-electronic devices. Today, the product line ranges from passivation glasses for semiconductors to special glasses for glass-to-metal and ceramic-to-metal seals and special glass tubes for reed switches and transponders. Technologies have also been developed that are of great importance for the housing technology in the fields of electronics, opto-electronics and sensor technology: precision blanking, glass-to-metal and ceramic-to-metal technologies, as well as special plating processes for improved surface finishes.

Specialty glass expertise

As a business unit of SCHOTT, we can offer our customers access to a wide variety of specialized glass types and 130 years of experience in glass development and processing for many different applications. More than 600 scientists and engineers are working for and with SCHOTT customers all over the world, while setting the pace by developing new, cutting edge technologies.





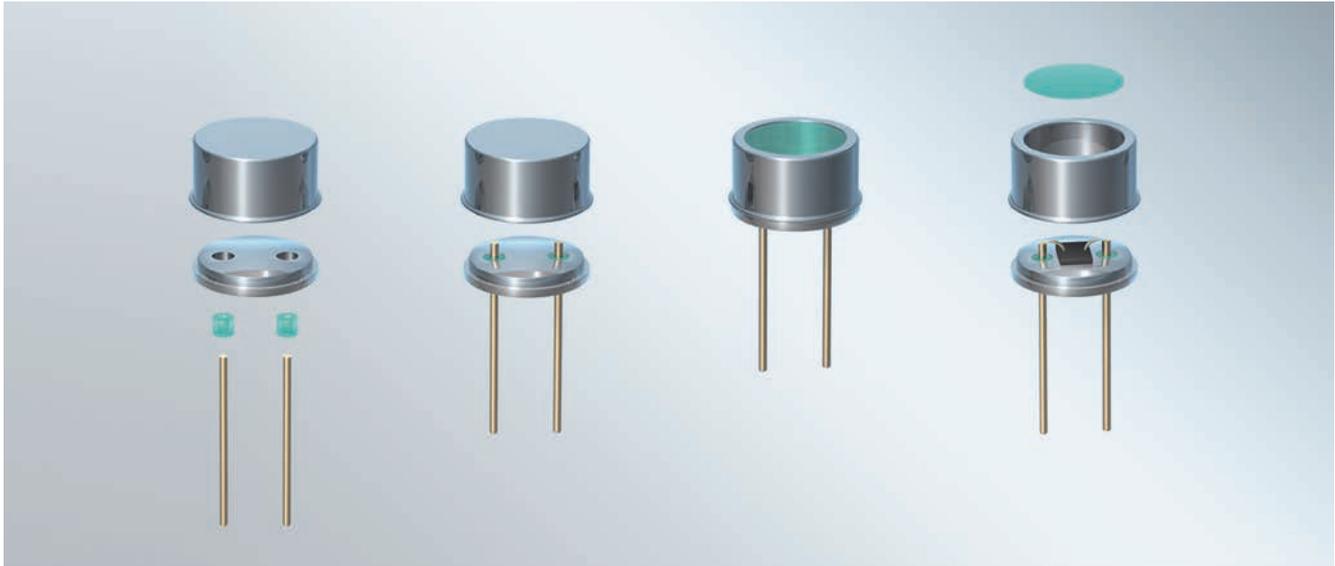
Business Unit Electronic Packaging

High quality products for a broad variety of challenging applications

Our customers are the world's leading suppliers of electronic devices for the automotive, aviation, data and telecommunications industry, as well as companies that manufacture consumer and defense electronics. We cooperate with the manufacturers of sensors, batteries, safety and control devices, MEMS, lasers, semiconductor wafers and many other products. Our large-scale hermetic feedthroughs are also used in liquefied natural gas (LNG) vessels and power plants.

Global Supplier

With 1,500 employees at four production locations and competence centers in North America, Europe and Asia, SCHOTT Electronic Packaging is a strong and reliable partner for customers worldwide. More than 5,000 different products have been developed and are distributed by SCHOTT. They are produced at company sites in Germany, the Czech Republic, Singapore, Japan and the US.



Introduction to Hermetic Packaging

Principles of Hermetic Packaging

How do you get electrical or optical signals in or out of a package that has been hermetically sealed? This challenge is something that many companies in the electronics industry must compete in every day. In this case, the key purpose of hermetic packaging is to protect highly sensitive electronics such as sensors, laser diodes, opto-electronic components, or airbag initiator propellants against corrosion, humidity, and other undesirable influences.

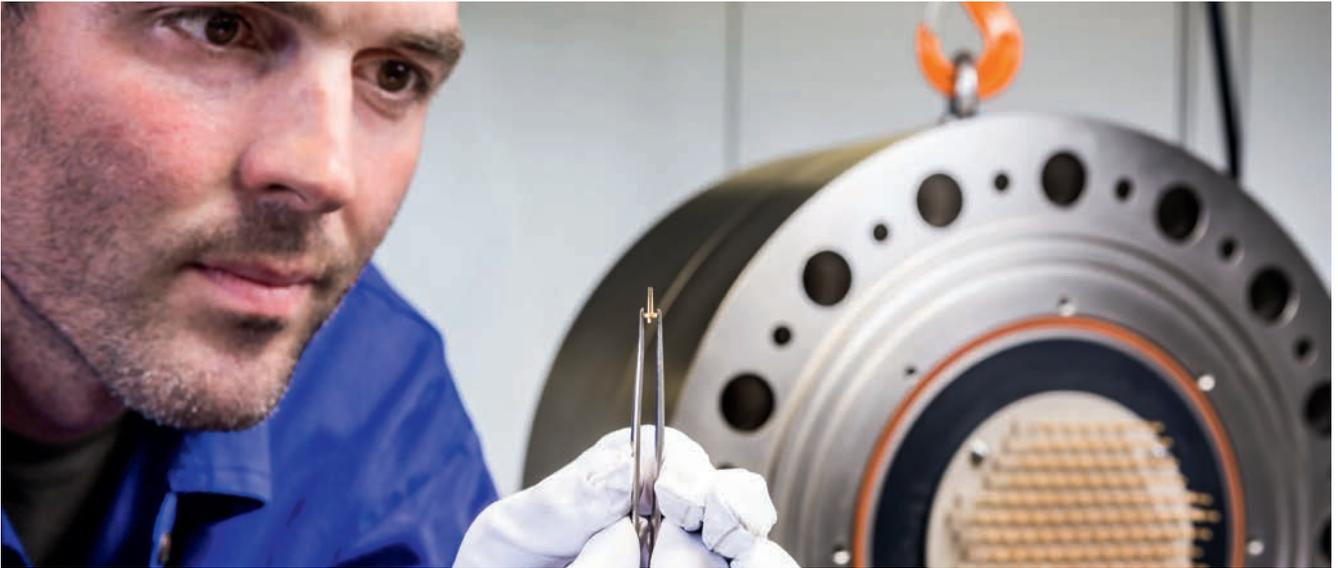
The best protection, a closed metal housing, is not the solution. In most cases, electrical current and light must be able to enter and exit the package. The electrical penetration is accomplished by guiding conductors through holes in the metal base and insulating and sealing them in position with melted glass to seal off the openings. The same applies to optical signals. Windows or lenses can be soldered onto or even melted together with the metal cap, or tubes can be provided to seal in glass fibers.

Today, encapsulating electronic components, such as microchips, is routine. The electronic components are usually connected to the pre-wired base by the manufacturer and then sealed by a cap or cover. This technology helps protect transistors, sensors, oscillating crystals, photo diodes, lasers, airbag igniters and entire hybrid circuits.

Hermetically sealed feedthroughs are even needed in larger sizes – to conduct electricity through the steel walls of ships with liquefied gas tanks, for example, or through containment walls of power plants. The main objective of all of these housings and feedthroughs is that the hermetic seals should remain intact long-term, even under the harshest conditions. They must protect sensitive contents against aggressive environmental media, as well as protect the environment from any negative effects of the substance contained in the package.

Proven Technology

For more than 75 years, SCHOTT has been developing, manufacturing and perfecting hermetic packaging components in which wiring is guided through metal and then insulated using melted glass. Extensive stress tests show that this bond remains completely sealed, even under the most difficult environmental conditions, enabling long lifetimes of even several decades for the enclosed electronic components. The airbag igniter that is designed to function reliably for the entire lifespan of an automobile is an excellent example.



From extremely small to large-scale

Hermetic packaging and sealing technology is suited for even the smallest housings that are not much larger than the head of a pin (1.2 millimeters) all the way up to high-voltage feedthroughs with diameters up to 600 millimeters.

Versatile Glass and Metal Uses

Glass-to-metal seals are the classic form of protection for sensitive components. Millions of these are put to use in many different industries, ranging from automotive to aviation, medical to telecommunications, and also electric power and defense. Because glass is so versatile, it can be used in a wide variety of different forms to provide hermetic protection for electronics.

For instance, in the field of opto-electronics, glass lenses or discs are integrated into metal caps using glass soldering. Passivation glass, on the other hand, serves to seal off complete components, such as diodes and microchips. Glass tubing segments protect reed switches that are activated by magnets, or RFID transponders that are read using microwaves.

SCHOTT supports its customers in selecting the appropriate glasses and suitable metal alloys for use in hermetic packaging.

Generally SCHOTT provides the basis for the metal package that features the electrical feedthroughs that are already insulated by melted glass, as well as the covers or caps made of metal that can also contain a glass window. The customer then connects his own electronic component and closes the housing by putting on the cover.

SCHOTT also offers sealing glasses as sintered preforms, passivation glasses in powder form and solder glasses in form of powder, preforms and pastes as separate product lines.

The brochure entitled "Technical Glass Handbook" is available in the Internet. The download section provides an overview of the relevant glasses that SCHOTT offers. Here, you will also find our company brochure with an overview of our products and our organizational structure.

The most important characteristics of glass-to-metal and ceramic-to-metal housings:

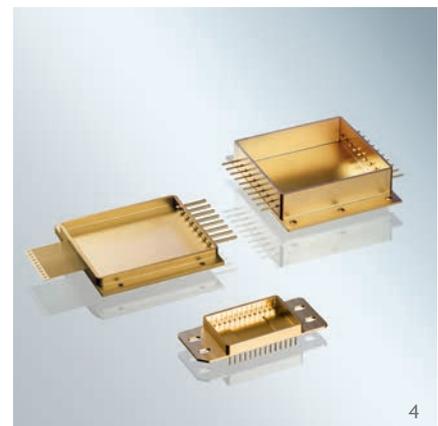
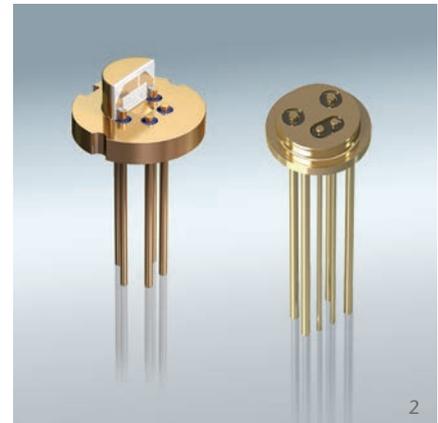
- High electrical insulation
- Hermeticity
- Pressure resistance
- Chemical resistance and protection against corrosion
- Wide range of service temperatures
- Mechanical stability
- Good heat conductivity, grounding and electromagnetic shielding
- Narrow tolerances
- Optical precision
- Low-loss transmission
- Suitability for joining connections using bonding, soldering or adhesives
- Easy installation of feedthroughs in housings, for example, by welding or soldering

A Wide Variety of Options

SCHOTT has developed more than 1,500 various types of hermetic products.

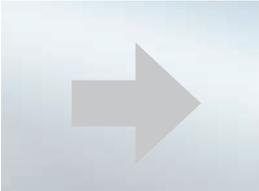
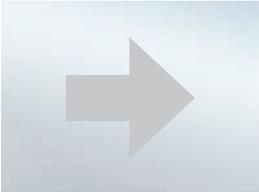
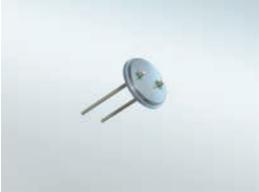
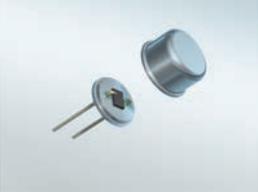
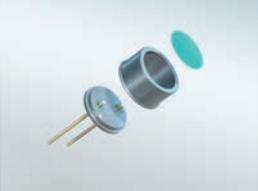
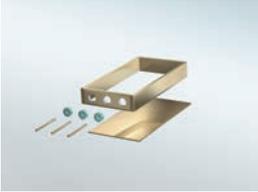
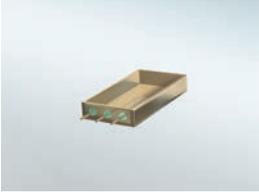
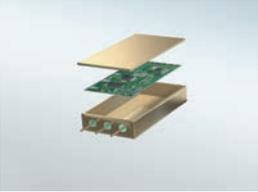
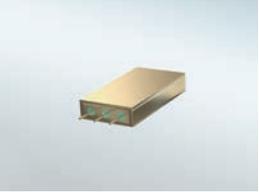
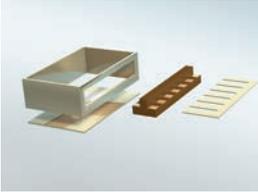
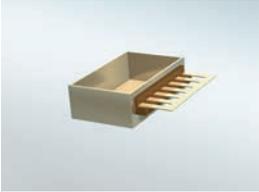
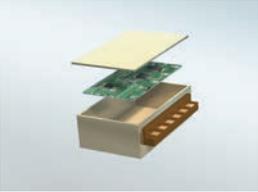
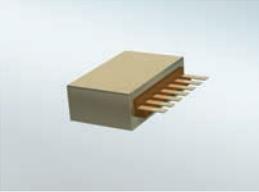
30 per cent of these are less than five years old – clear proof that the application potential of this technology is far from being exhausted, but also proof of the high degree of innovation of SCHOTT Electronic Packaging in cooperation with the staff of the Otto Schott Research Center in Mainz (Germany).

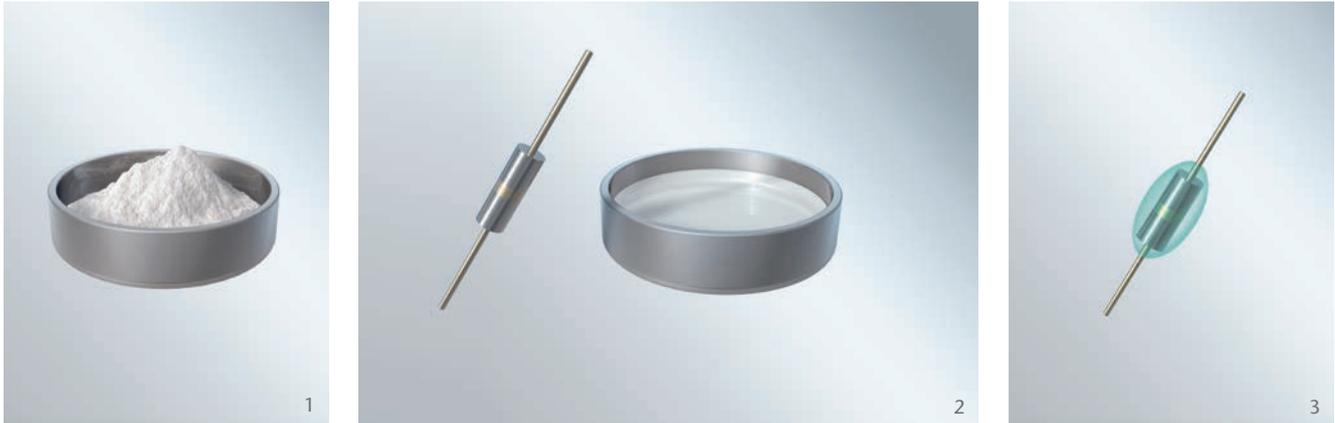
SCHOTT develops customized and cost-effective solutions in close cooperation with the customer and constantly introduces new ideas and solutions. Ceramic-to-metal feedthroughs are new to the product line at SCHOTT. These are used in telecommunications housings that must be able to guarantee high data rates or require complex wiring in extremely small areas and special electrical properties.



- 1 | Specialty glass powders, sintered preforms and precision-cut tubes
 2 | TO headers
 3 | Opto caps and lenses
 4 | Microelectronic (Hybrid) Packages

Basic Housing Principles

Product	SCHOTT		Customer	
	Materials	Assembly	Assembly	Closure
Passivation glass				
Transponder glass				
Reed glass				
TO Header				
TO Opto-Cap				
Glass-to-metal sealed micro electronic package				
Ceramic-to-metal sealed microelectronic package				



Passivation Glass

For chemical and mechanical protection of semiconductor surfaces

Passivation of Semiconductor Components

Semiconductor components made of silicon (Si) or gallium arsenide (GaAs) are sensitive and require protection against damage, soiling, humidity or aggressive chemical substances. For this reason, it is quite common today to protect diodes, integrated circuits, power rectifiers and many other semiconductor components with a cover made of glass – a concept better known as passivation. At the same time, glass is expected to do more than just provide protection. It is also designed to stabilize the electric properties of the component by positively influencing the blocking voltage and reverse current.

Purity Requirements

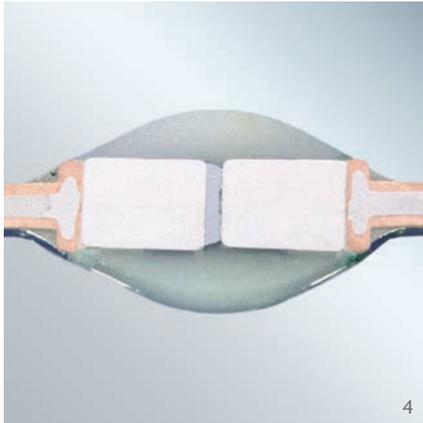
Good passivation glasses must have special chemical characteristics. For example, they do not interfere with the properties of p-n junctions in semiconductor components. One of the most important requirements is that passivation glasses must be nominally free of alkali ions. Due to their high mobility particularly at elevated temperatures, alkali ions could diffuse from the glass into the semiconductor material and have a negative effect on the electrical characteristics. For this reason, SCHOTT uses only glasses that contain pure raw materials, in which the share of sodium oxide (Na₂O) and potassium oxide (K₂O) each remains under

50 ppm and under 20 ppm for lithium oxide (Li₂O). For certain metals that are also undesirable in semiconductors, even lower limits apply. For example, with copper oxide (CuO), the concentration in passivation glasses from SCHOTT is less than 10 ppm. If necessary, the limits can also be considerably lower. Furthermore, these glasses contain no iron.

The glass formula is carefully selected from the broad range of standard glasses available or specifically formulated to meet the exact requirements of the customer. Here, SCHOTT ensures that the glass formula is compatible with the maximum operating temperature of the electronic component. After all, at high temperatures, the charge carriers move much more inside the glass and the electrical characteristics of the semiconductor may suffer.

Lead-free Preferred

Conventional passivation glasses contain lead oxide that provides extremely high electrical insulation. However, lead causes harm to the environment; therefore global efforts to reduce its use deserve support. Early on, SCHOTT developed lead-free glasses that still meet stringent requirements in respect to insulation.



- 1 | Passivation Glass (in powder form)
- 2 | Semiconductor component before passivation
- 3 | Semiconductor component after passivation
- 4 | Diode passivation
- 5 | Solder Glass

For sintered glass diodes usually a slurry of the glass powder with deionized water is applied to the diode body including the Mo- or W-contact studs. Then, the component is dried and sintered, whereby the glass forms a hermetic protective layer. This glass layer meets the highest requirements for insulation, acid resistance, dielectric breakdown resistance and adaption to expansion.

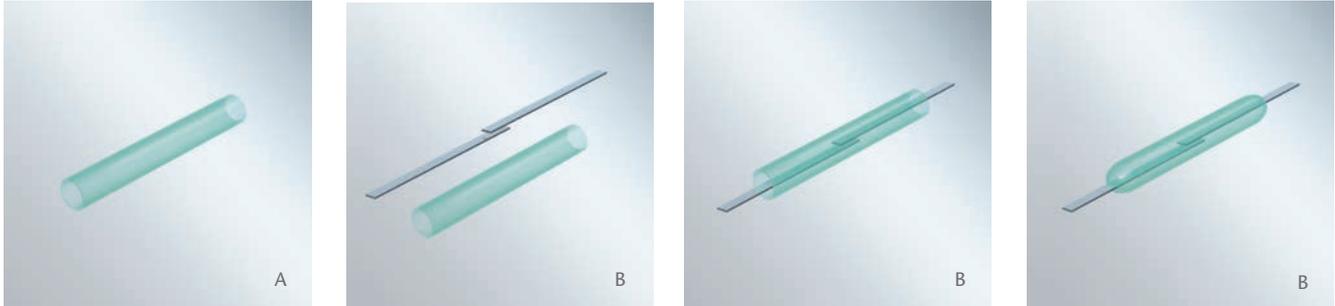
Wafer Passivation

For each degree Kelvin temperature difference, silicon expands by only around one three-millionth. Although there are glasses that exhibit thermal expansion that is similarly low, these have such a high melting point that they are not suited for use in coating semiconductor components. Mechanical stresses that result from the differences in expansion during application and cooling down of the melted glass cannot be completely avoided. The worst possible case for a large wafer to be passivated is that the disc becomes curved and breaks or cracks during

cooling or separation of the components. For this reason, SCHOTT offers composite glasses with low coefficients of thermal expansion (CTEs) in order to minimize the CTE mismatch between the glass layer and the silicon wafer. Thin glass layers also reduce the warpage of the sandwich. This is why SCHOTT recommends maximum thicknesses for all homogeneous passivation glasses. Slow cooling near the transformation temperature at which the melted glass becomes rigid again, prevents cracks as well.

Appropriate Grain Size

SCHOTT supplies passivation glass for the protection of semiconductors as low abrasion, ground glass powder in the grain categories K1 to K6. For passivation of integrated circuits using layers that are less than ten micrometers thick, SCHOTT recommends grain sizes FK 3.5 and FK 1.5. Coarser grain sizes of K3 to a maximum of K4, used in aqueous suspensions, cover components such as sintered glass diodes.



Reed glass
 A | SCHOTT Product
 B | Customer Assembly

Reed Glass

Highly reliable encapsulation of reed switches over millions of switching cycles

They can be found in the centralized locking systems of automobiles, as belt sensors or as switches in hot water boilers: reed switches are popular workhorses in the electronics industry, because they open and close electrical circuits without any mechanical influence from the outside. A weak magnetic field presses two metal contact blades together inside a thin glass tube and thus establishes contact. In resting state, a reed switch does not require any power. This is important for devices that use very little power. Because they contain no mechanical control, reed switches can handle many millions of make-and-break cycles without wear.

To ensure the functionality, the metal blades must be free of dust and hermetically sealed inside glass tubes with an inert gas. This must be done as quickly as possible and with tight tolerances. Selecting the proper glass, as well as sophisticated testing methods, ensures that no tension results between the glass and the wiring at the end of the housing during sealing. The 8516 is SCHOTT's main reed glass type. This greenish, leadfree glass contains iron oxide and, therefore, absorbs infrared light particularly well, whereby the maximum absorption of the light takes place at a wavelength of 1.1 micrometers. This means that, once the ends of the tube have been equipped with the connections of the reed contacts, the customer can melt and seal them off using only light without a flame, a neodymium-YAG laser or mercury vapor lamp, for instance. This way, no impurities can enter the glass tube during the heating process.

SCHOTT has developed an extremely precise scribe and break process for the manufacturing of the tubing sections. During this process a gas flame is used only after the tubes have been sawn. The ends are then perfectly fire polished by



Reed glass with two open fire-polished ends

heating them up for a short time. The 8516 glass type features particularly low vapor pressure. This is an advantage, because no impurities are permitted to enter the inside of the glass tube during sealing at temperatures over 1000 °C.

In order to ensure the highest precision, SCHOTT developed all of its processing machines on its own. Typical glass tubes for reed switches are between one and five millimeters thick and five millimeters to several centimeters long. The tubes are washed and packaged in antistatic containers that even satisfy clean room standards for quality, if desired.



Transponder Glass

Transponder Glass

Hermetic and biocompatible packaging of RFID transponders

Besides reed switches, also more complex electronic devices can be hermetically encapsulated in glass tubing, for example RFID transponders. RFID stands for Radio Frequency Identification and refers to small microchips that have antennas, that store data and disclose it again when a nearby reading device sends out radio frequency electromagnetic waves. The range lies between several centimeters and one meter. RFID chips are normally sealed in paper or film and contain the fingerprint and passport photo in biometric identification documents, the sender and recipient of postal packages, or signatures for books that have been borrowed from libraries.

However, some RFID transponders require a glass cover to protect the chip against oil or acids, as in automotive manufacturing, for example. Yet another example can be found in the area of livestock breeding, where the transponder is implanted beneath the skin of an animal. The chip provides information on the owner and origin of the animal and, thus, provides consistent information on the source of the meat.



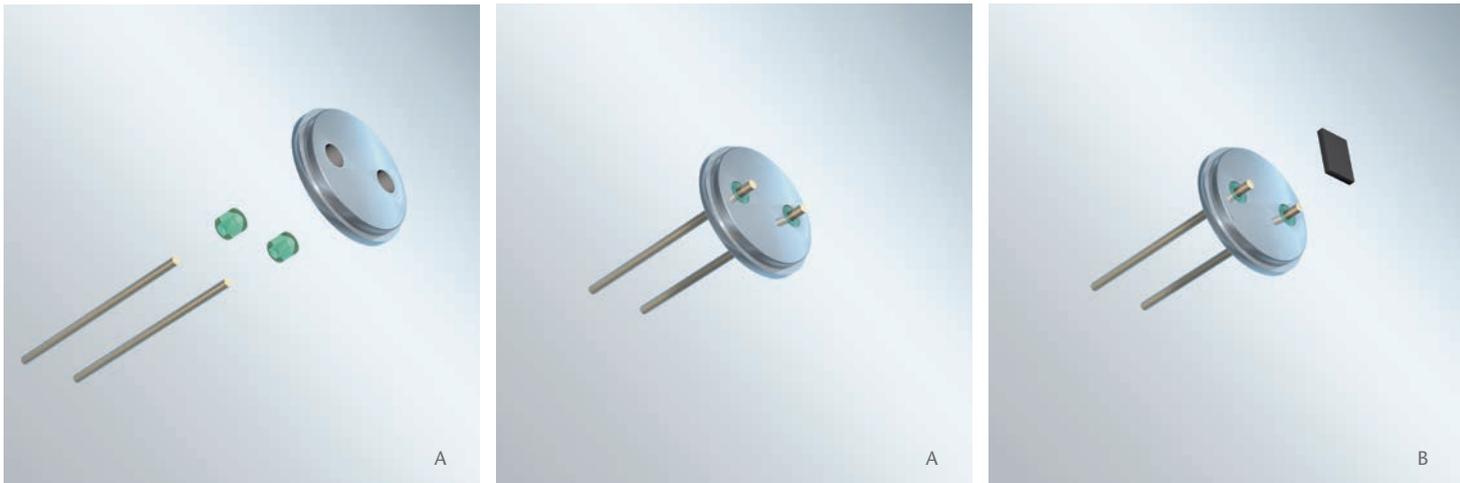
Transponder glass
 A | SCHOTT Product
 B | Customer Assembly

In the same way, the routes of migratory birds can be followed and traditional dog collars can be replaced by an RFID chip under the skin. For its transponder glasses, SCHOTT relies on its patented 8625 glass, a type that is extremely biocompatible and behaves neutrally when inside the body of an animal.

Transponder glass from SCHOTT contains a high portion of iron oxide to ensure that the tube can be sealed using various infrared light sources without contamination. Because RFID transponders contain no electrical connections, SCHOTT supplies the tubes with one end already closed and the other end open and flame-polished so that no glass splinters result during transportation. The customer guides the RFID chip into the one to eight millimeter thick tube and closes the other end hermetically by heating it up with light from a neodymium-YAG laser or another appropriate light source.

What applies to reed glasses also applies to transponder glasses; SCHOTT supplies the tubes in standard sizes and in custom sizes to customers' specifications. The glasses are packaged inside antistatic transportation boxes, and in clean room conditions, if desired.

Customers can easily hot form and hermetically seal the open end as the maximum intensity of IR radiation is absorbed at 1.1 μm wavelength. The presence of a portion of Fe_2O_3 makes these glasses appear green. At appropriately high IR intensities, they require considerably shorter processing times than flame-heated clear glasses.



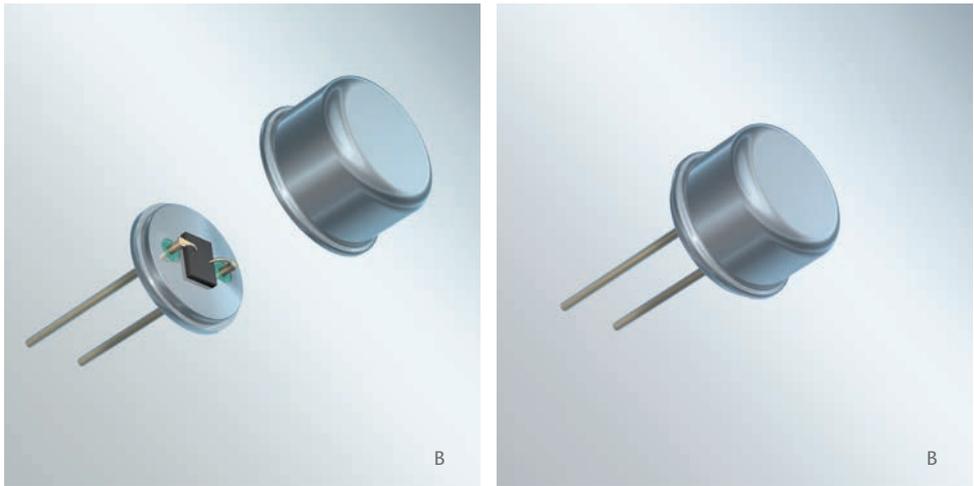
Glass-to-Metal Sealing (GTMS)

Glass and metal perfectly combined: for the most demanding applications

SCHOTT offers some 1,500 basic versions of hermetic feedthroughs; however, the technology used to create them is always quite similar: metallic conductors penetrate through a metal housing that contains several openings. Sintered glass rings or glass tubing segments are melted around the conductors to provide electrical insulation, enhance mechanical strength and center the conductors in the openings. There are two primary ways to fuse glass and metal: the matched glass-to-metal seal or the more commonly used compression glass-to-metal seal.

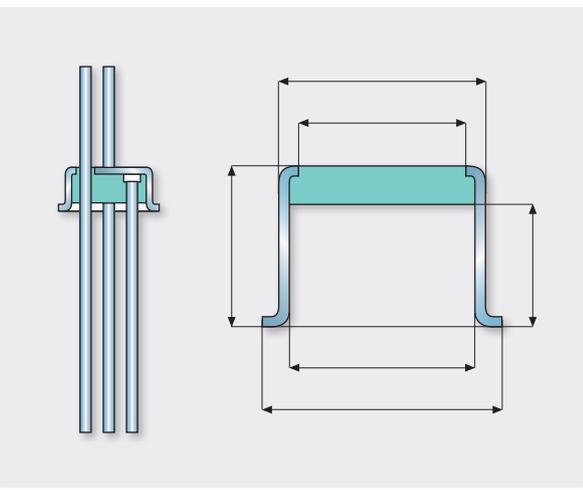
Matched Glass-to-Metal Seals

For many sensitive semi-conductor and opto-electronic applications, it is very important that all components from the lens to the semi-conductor device expand and contract with temperature at very similar rates. This ensures that neither stresses nor optical misalignments are introduced into a working device during the assembly or its final operation. The products utilizing this technology must operate over large temperature ranges and continue functioning flawlessly after tens of thousands of thermal cycles. SCHOTT accomplishes this by combining glass and metal with similar thermal expansion profiles in a clever manner to ensure that the glass-to-metal feedthrough contains virtually no stresses at room temperature or at the working temperature of the final product.

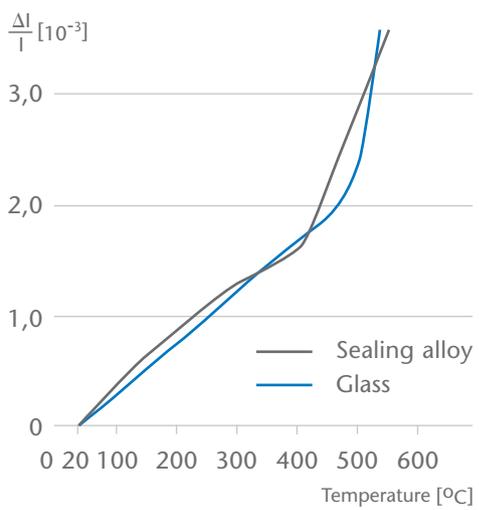


TO Header and Cap
 A | SCHOTT Product
 B | Customer Assembly

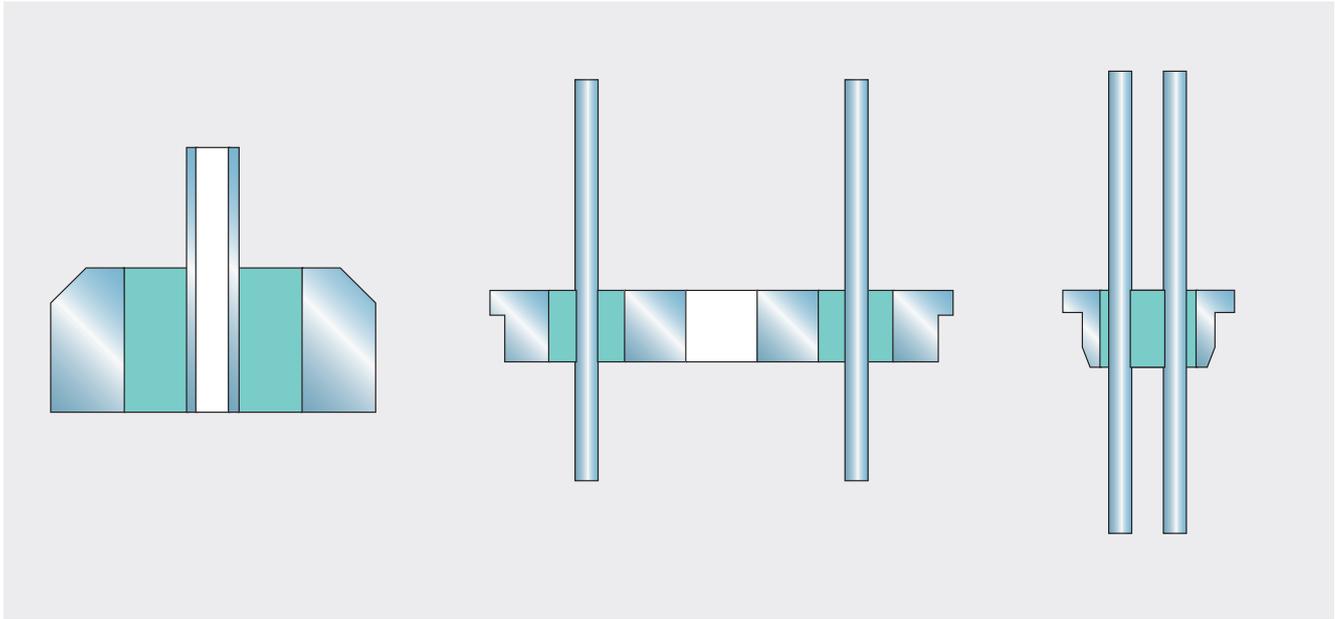
Advantages of this type of seal are that more conductors can be placed into a given housing area temperature and that thinner material cross sections can be used, making the part lighter in weight. Matched glass-to-metal seals are available with hard glasses (for example, 8250 glass) and soft glasses (for example, 8630, 8350, 8421, 8422 glasses), each in combination with appropriate metal alloys. In the event that sudden or isolated deviations occur during sealing or later in use, hard glasses should be chosen, because they experience lower stresses.



Typical design of matched glass-to-metal seals



Relative thermal expansion of the components of a matched glass-to-metal seal (glass 8250 - NiCo 2918)



Typical designs of compression glass-to-metal seals

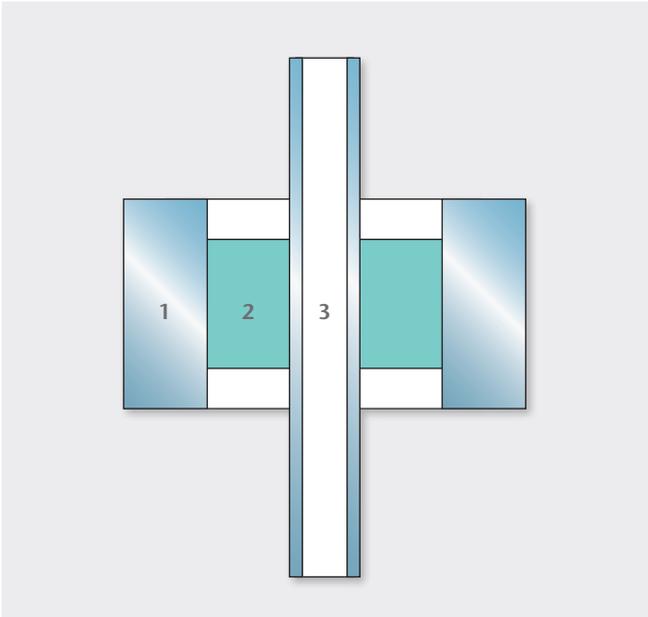
Glass-to-Metal Sealing (GTMS)

Compression Glass-to-Metal Sealing

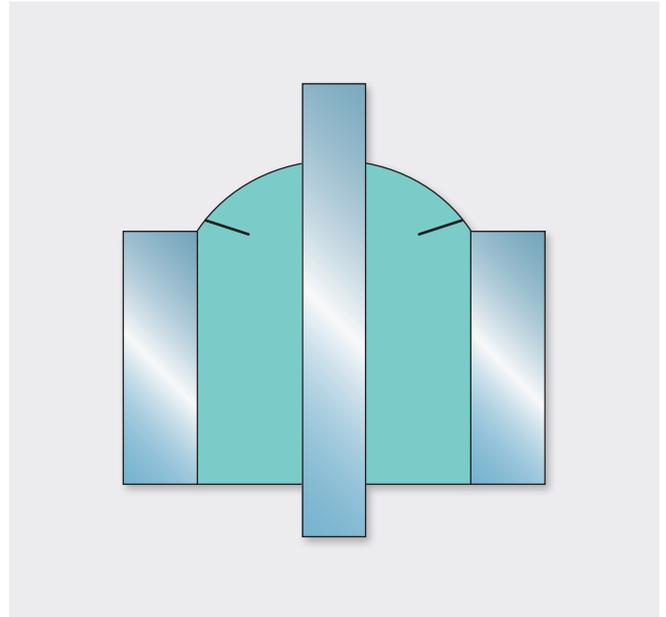
If corrosion resistance, pressure capability, or conductor strength are more important parameters in your product than thermal expansion matching, then a compression glass-to-metal seal may be better suited for your application. In matched glass-to-metal seals, stress inside the glass is avoided. With compression glass-to-metal seals a specific type of stress is purposely designed into the part.

Compressive Loading of the Glass

Glasses have a compressive strength that is ten to twenty times higher than its tensile strength. This compressive force can be leveraged to improve the feedthrough strength by selecting metals for the housing with a coefficient of thermal expansion that is much higher than the value of the glass and interior conductor. Due to this higher thermal expansion, the metal housing shrinks firmly onto the glass during cooling to create a hermetic seal. In fact, compressive loading of the glass and conductor occur to such a high degree that the metal remains firmly on the glass, even if mechanical pressure is applied or the temperature changes dramatically. SCHOTT utilized this technique for the first time in 1941 to seal transmission tubes. Since then, SCHOTT has developed many combinations of glass and metals to meet the most demanding applications throughout the world.



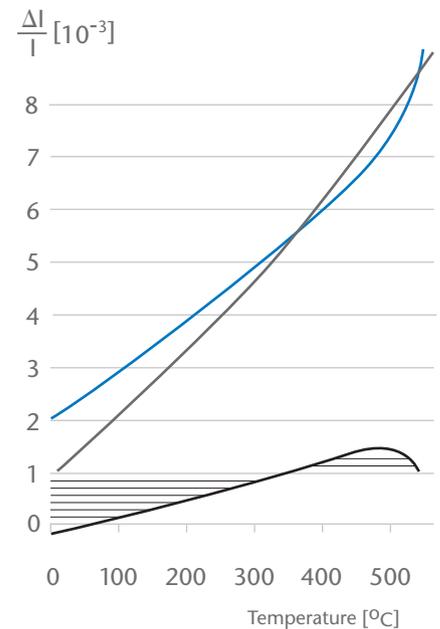
Schematic representation of a compression glass-to-metal seal
1 = External lead | 2 = Glass | 3 = Internal tubular lead



Cracks in the glass body of a compression glass-to-metal seal in which the glass body is protruding beyond the sealing plane.

Minimum Metal Thickness and Height

In a compression seal, much greater forces develop inside the metal during the sealing process. These forces make it necessary to increase the amount of metal around each feedthrough to support the hermetic seal. Here, SCHOTT has decades of experience optimizing the material combinations and provides assistance to properly dimension the key characteristics. Generally, the wall thickness of the pressure ring should be a minimum of 0.5 millimeters, and its height should be at least 1.5 millimeters. Glass rims that protrude from the melting opening and increase electrical insulation resistance are not possible with compression seals, because cracks could result from the reduction of forces outside of the melting zone. For this reason, the sintered glass is usually selected to be somewhat shorter than the feedthrough and does not end flush with the metal, but rather is located somewhat deeper, once it has cooled down.



— Steel
— 8421
— Radial tension

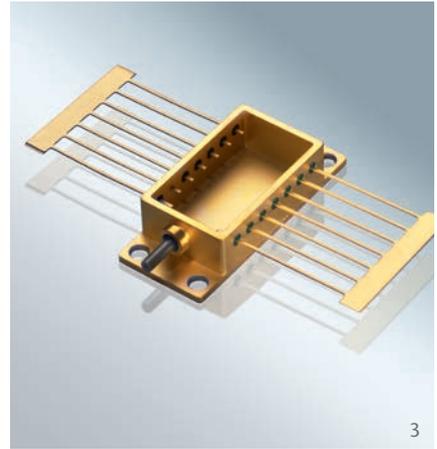
Relative thermal expansion of the glass and metal (compression ring) of a compression glass-to-metal seal.



1



2



3



4



5

Glass-to-Metal Sealing is the technology of choice for a broad variety of product types and packaging footprints:

- 1 | TO-based header
- 2 | Connector
- 3 | Microelectronic package
- 4 | Compressor seal
- 5 | Housing for Gyro Sensor

Glass-to-Metal Sealing (GTMS)

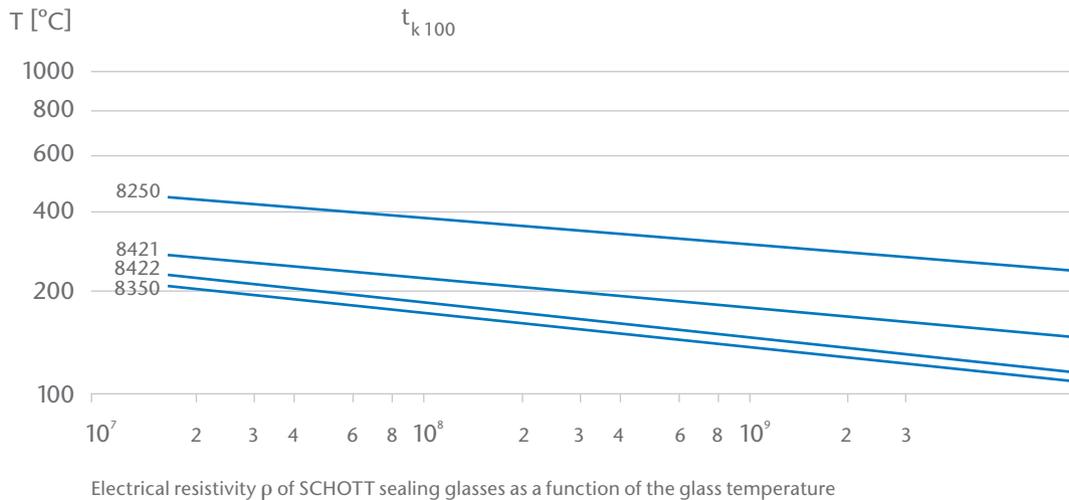
Technical properties of glass-to-metal seals

Hermeticity

In order to ensure that glass-/ceramic-to-metal seals are, in fact, hermetically sealed, SCHOTT conducts routine testing. In this test a feedthrough is mounted onto a vacuum leak detector and sprayed with helium gas. A mass spectrometer is then used to search for helium leaking into the vacuum area through leaks in the feedthrough. This measurement technique is capable to detect leakage rates down to 10^{-12} millibar x liters per second only under laboratory conditions. Even though SCHOTT feedthroughs are hermetic in these extreme ranges, regular test operations focus on the practicable 10^{-8} millibar x liters per second standard based on the measuring technique. SCHOTT can guarantee improved leak rates for most products. The low leak rates of glass-to-metal-packaging from SCHOTT cannot be achieved with packaging techniques, such as plastic/epoxy resin housings, and are not exceeded by ceramic-to-metal housings.

Electrical Insulation

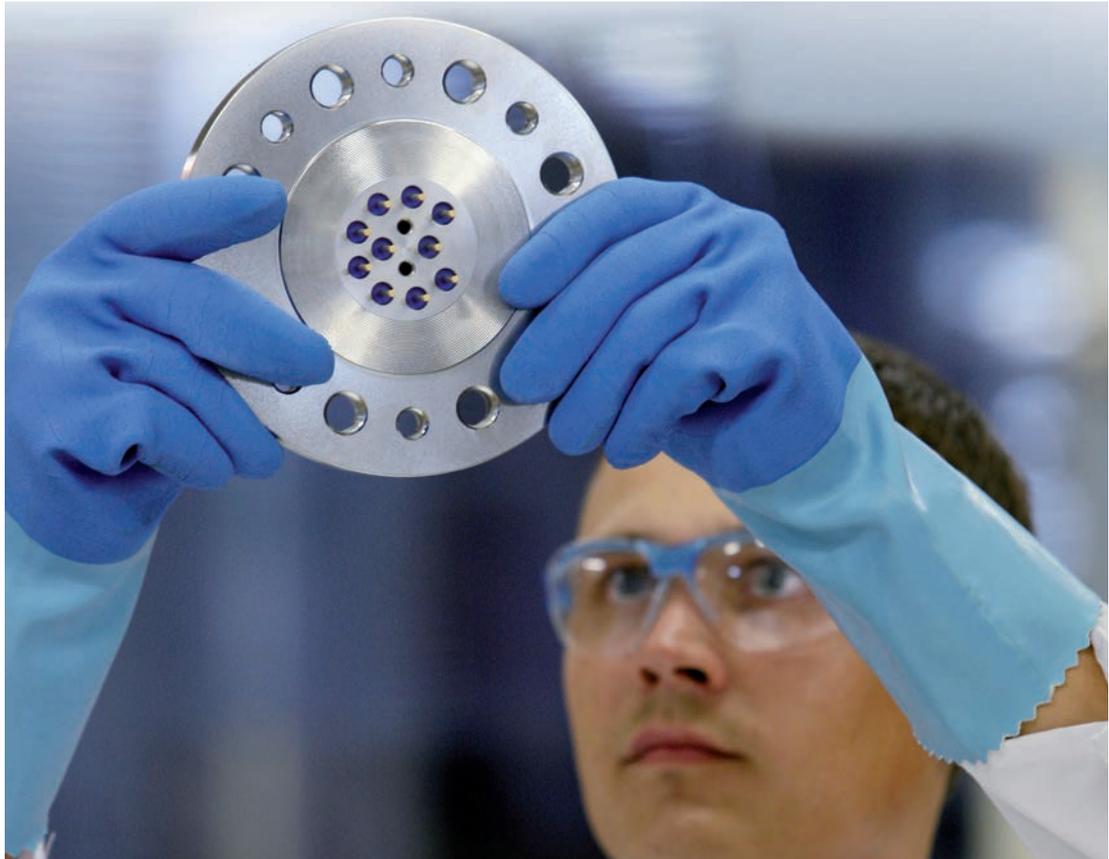
Glasses from SCHOTT for glass-to-metal-feedthroughs are excellent insulators. The specific electrical resistivity can range up to 1020 ohm cm. At room temperature, however, surface resistance is crucial. This is much lower and is determined by the humidity that condenses on top of the glass surface. Glasses with higher chemical stability, such as those used by SCHOTT, store less water and, therefore,



have a higher surface resistance. Under normal conditions, the total insulation resistance lies between 1010 and 1012 ohms, depending on the glass type, and is largely independent of the creepage path length that the current needs to take. Even higher insulation resistance is possible, for instance, for use in tropical, humid climates. In this case, SCHOTT uses special techniques to treat surfaces. At very hot temperatures, the water skin on the glass surface disappears almost completely and the electrical resistance is determined solely by the extremely high volume resistivity. However, this resistance declines with rising temperatures (see graphic below). Nearly the same applies to the flash-over resistance: the dielectric strength of 20 kilovolts per millimeter is very high, whereas the flashover resistance, which is determined by the creepage distance between the metallic parts that transmit voltage, is approximately 1 kilovolt/mm.

Dielectric Properties

Standard glass-to-metal feedthroughs have a self-capacitance of between 0.5 and 3 picofarad. The measurement is made at a frequency of 1 megahertz at room temperature. The self-capacitance depends on the dielectric properties of the glass and the geometry of the glass feedthrough. Upon customer request, it can be set within certain limits with an accuracy of 10 percent.



Glass-to-Metal Sealing (GTMS)

Additional properties and processing recommendations of GTMS

Glass Colors

SCHOTT is able to utilize different oxides to dye the glasses used in feedthroughs to green, blue, brown or black, if desired. This makes it easier for the customer to differentiate between various similar housings and/or identify electrical connections during assembly. The properties of the glass seal, for instance, hermeticity or seal strength, do not change as a result of coloration.

Temperature Behavior

Both matched and compression glass-to-metal seals are designed to operate within designed temperature ranges. When the temperatures are taken above or below the design range, damaging stresses can begin to form in the feedthroughs. Even closing housings with caps or covers or installing feedthroughs in the walls using soldering or welding, inevitably results in an increase in the temperature of the housing. Because sealing glasses have extremely low heat conductivity, while metals have high heat conductivity, the metal expands more quickly than the glass. Tensile forces due to these temperature differences may build up between the glass and the metal and can lead to breakage of the glass-to-metal bond or even cracks in the glass, in a worst case scenario.

A General Rule

Tensile stresses during heating should be avoided as much as possible; however, such stresses are not harmful as long as they do not exceed a limit of 20 to 30 megapascals. This can be achieved by selecting the proper materials and controlling any heating processes.

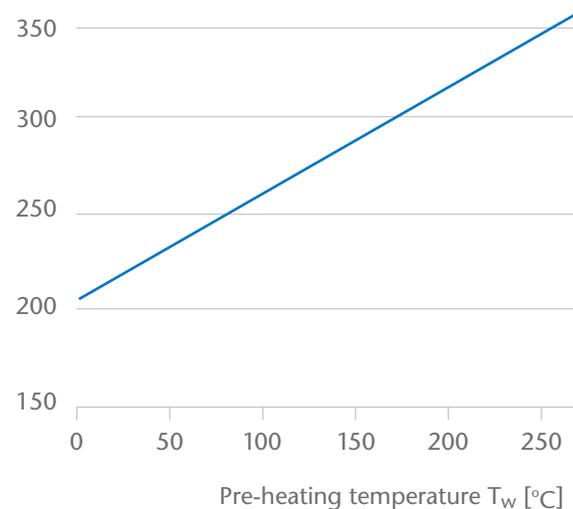
How Tensile Stress Is Avoided

If, for example, the metal part is to be heated up to a high temperature during installation, then low expansion, hard glasses are more appropriate, because they experience lower tensile stresses at increasing temperatures than high expansion, soft glasses. For this reason, for matched seals that contain soft glass, SCHOTT recommends pre-heating the entire component. However, pre-heating is also recommended for compression seals that need to be heated up significantly during installation. The adjacent graphic illustrates how the so-called inversion temperature (when compressive strength and tensile strength are zero) increases with increasing pre-heating of the compression seal.

Temperature Limits

Glass-to-metal feedthroughs from SCHOTT are capable of withstanding temperatures of $-65\text{ }^{\circ}\text{C}$ and up to $+250\text{ }^{\circ}\text{C}$ with compression seals and a T_{max} of $< 400\text{ }^{\circ}\text{C}$ with matched seals. Special designs and careful choice of metal components allow usage temperatures at cryogenic levels of $-200\text{ }^{\circ}\text{C}$ or even below also with iron-nickel-cobalt types. Higher temperatures are possible as well. Ceramic seals are capable of withstanding usage temperatures up to $600\text{ }^{\circ}\text{C}$. Upon request, SCHOTT can conduct testing in which the temperature resistance and the reaction to rapid shifts in temperature of glass-to-metal feedthroughs are determined.

Inversion temperature T_i [$^{\circ}\text{C}$]



Inversion temperature T_i of a standard 8422 compression glass seal as a function of the preheating temperature T_w .



Preforms are manufactured in several stages:

Grinding: Ball mills produce a powder from cullets with an average grain size of between 10 and 20 micrometers.

Granulation: Binding agents and spray granulation make the powder flowable and suitable for pressing.

Pressing: A pressing tool converts the glass powder into the desired form. This technique allows for relatively open geometries and narrow tolerances that would be impossible with hot forming techniques.

Sintering: The glass preforms pass through special furnaces, where the binding agents evaporate and leave the finished glass part. During this process the preform also shrinks in size.

Glass-to-Metal Sealing (GTMS)

Small details with a great impact

Sintered Preforms (Molded Glass Parts)

Sintered preforms play a decisive role in ensuring the exceptional properties related to hermeticity, electrical insulation and mechanical strength of glass-to-metal feedthroughs. Manufacturing these requires considerable know-how that SCHOTT has obtained over decades. In most cases, the preforms are fused together with the metal bases at SCHOTT to produce the finished feedthrough. The sintered preforms are known for their high dimensional accuracy, mechanical stability, consistent weight and smooth surfaces. SCHOTT not only manufactures preforms for in-house use but also offers them to customers. Applications for preforms are widespread, including e.g. sealing of flash lamps. A wide variety of different designs is possible.

Tube sections

In addition to sintered glass parts, SCHOTT also uses short sections of glass tubing for sealing. These remain transparent even after they have been remelted. They are used in the glass-to-metal feedthroughs where inspection of the glass-to-metal seal or low bubble content may be important.

The Surfaces of Metals

With glass-to-metal feedthroughs, it is not only important to use the proper glass, but the metals used for the housing also have a significant impact on the durability of the component. For this reason, SCHOTT has worked diligently to perfect processing of metal housings and offers its customers extensive expertise on the proper housing materials to use, with respect to resistance to corrosion or characteristics related to bonding and soldering, for example.

Layer Features	Electroless nickel	Electrolytic nickel	Nickel sulfamate	Hard gold	Pure gold	Immersion gold	Electroless gold	Matte tin
Resistance weldability	●	●	●	●	●	●	●	●
Laser weldability	●	●	●	●	●	●	●	●
Roll seam weldability	●	●	●	●	●	●	●	●
Solderability	●	●	●	●	●	●	●	●
Wedge-wedge-bonding	●	●	●	●	●	●	●	●
Ball-wedge bonding	●	●	●	●	●	●	●	●
Ductility	●	●	●	●	●	●	●	●
Corrosion resistance	●	●	●	●	●	●	●	●

- Excellent ● No experience ● Special experience
 ● Good ● Not advisable ● Wedge-wedge bondable with gold flash

Combined Platings To plate with:	Electroless nickel	Watts nickel	Nickel sulfamate	Hard gold	Pure gold	Immersion gold	Matte tin
First layer							
Electroless nickel			●	●	●	●	●
Watts nickel			●	●	●		●
Nickel sulfamate			●	●	●		●
Electrolytic copper	●	●	●				●
Electroless copper	●					●	

Surface Cleaning

To achieve the desired characteristics, the metal surface must be chemically or galvanically cleaned, coated and refined. Initially, impurities such as cooling lubricants, drawing greases, corrosion protection materials, metallic dust and metal oxides must be removed so that the metallic protective layer adheres properly. Various techniques can be used in cleaning, such as grinding, sand-blasting, solvents for removing grease, alkaline solutions for electrolytic precision cleaning or etching with inorganic acids.

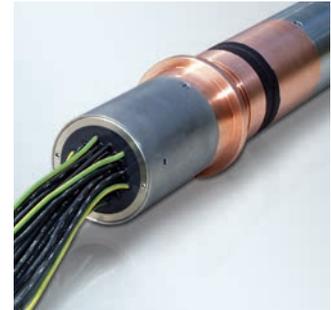
Coating Techniques

Coating metals for use in glass-to-metal or ceramic-to-metal seals or the finished feedthroughs themselves requires dipping them into an aqueous solution for a defined period of time. This electrolyte contains metals, such as nickel, silver, gold, copper or tin, dissolved as salts that are deposited on the metallic surface of the housing. SCHOTT has many years of experience in optimizing the key parameters such as electrolyte concentration, temperature, current density or the pH value.

The two primary methods for coating are:

During galvanic deposition, electrical direct current voltage causes metal ions to migrate toward the cathode and be deposited on the component.

During chemical deposition, a reducing agent, rather than an electrical current, causes positively-charged metal ions to be neutralized by negative charge carriers and then be deposited onto the metal of the package. In this way, even packages with complex structures can be uniformly coated within tight tolerances with high corrosion resistance.



Glass-to-Metal Sealing (GTMS)

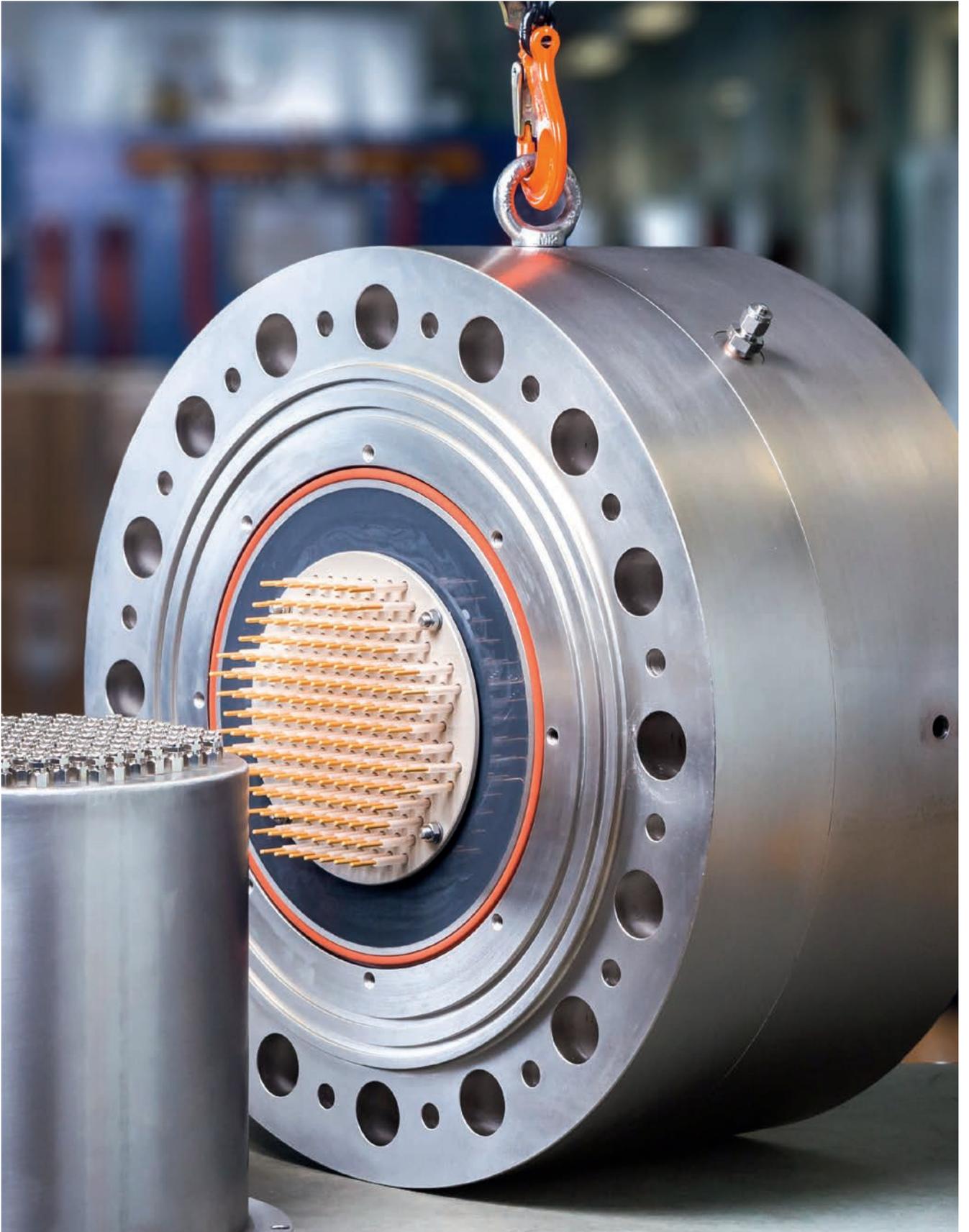
Energy Applications

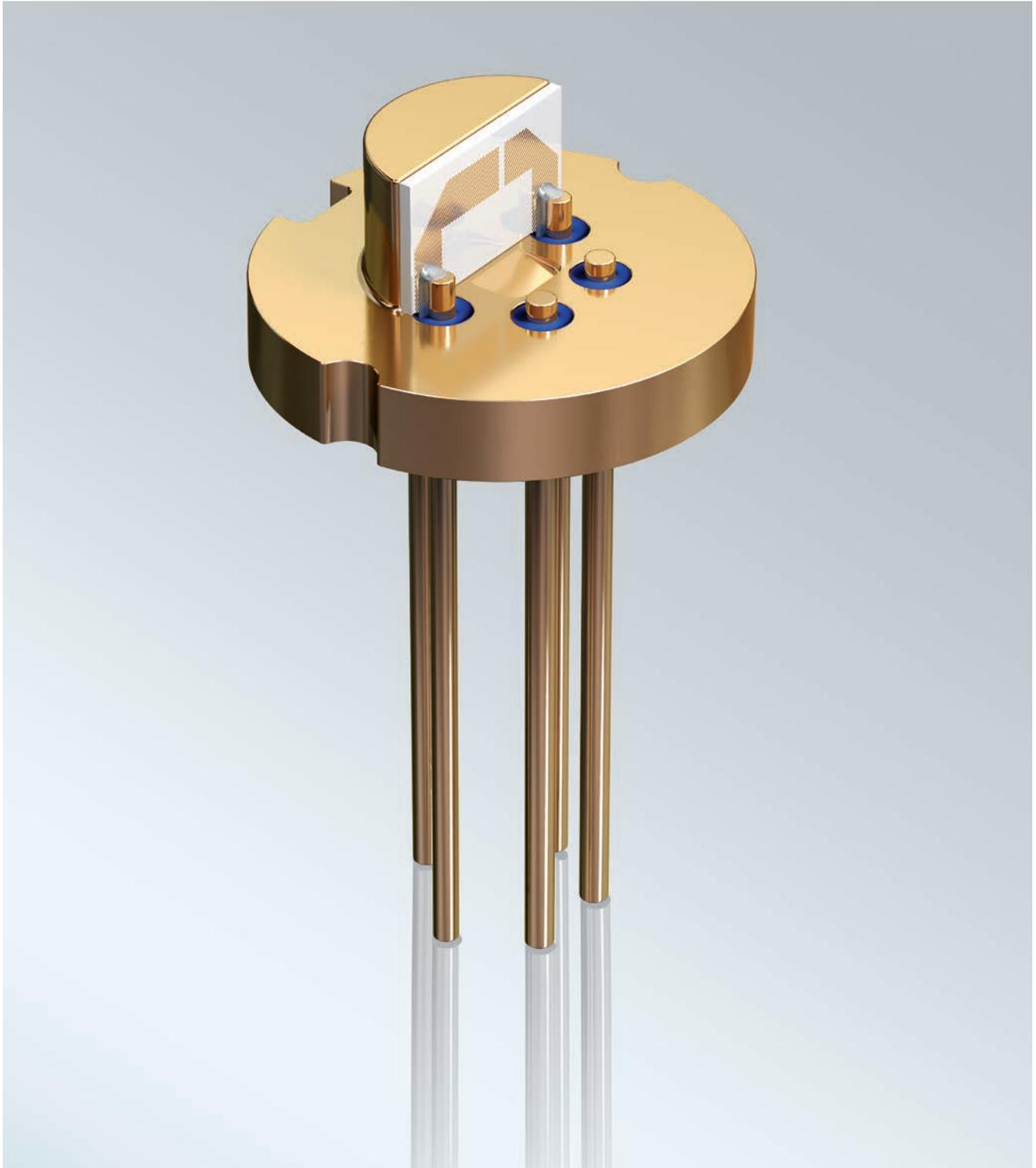
Terminal headers and electrical penetration assemblies

The demand for natural gas is increasing, along with the need for suitable means of transporting it. Instead of relying only on pipelines, gas producing and consuming countries are also increasingly using ships to transport this raw material, which has been liquefied by chilling it inside huge, spherical tanks. Today, several hundred of these ships are now sailing the world's oceans. For shipping, the natural gas is chilled to $-100\text{ }^{\circ}\text{C}$ or below, liquefied and then pumped into the tanks on the ships. Compared with storage at normal temperature, this allows a 600-fold quantity of gas to be stored. During this process, the liquefied gas is under high pressure of up to 150 bar. The power cables for the pumps operating inside the tank, which are fully immersed in the liquefied gas, must also function under these low temperature conditions and remain perfectly sealed.

As the feedthrough of electrical cables to the submersible pump is a critical point, SCHOTT applies the most stringent safety requirements during production. As a result, all types have been certified according to the European ATEX standard and the international IEC standard for electrical safety. Prior to shipment, each component is tested with one and a half times the maximum required pressure and then tested for leak tightness with helium. A high voltage electrical test ensures that no short circuits subsequently result when voltages up to 13,800 volts and currents up to 1,500 amperes flow through the electrical connections in the glass feedthrough.

SCHOTT also manufactures feedthroughs for power plants for example, for the new generation of nuclear reactors. In nuclear power plants and nuclear powered submarines, feedthroughs are used to transfer measurement data from the reactor or to supply high currents to operate systems within the reactor pressure vessel. In addition, fiber optics now can also be fed through, using a SCHOTT patented process.





TO PLUS® headers are available with data rates of 28 GBit/s



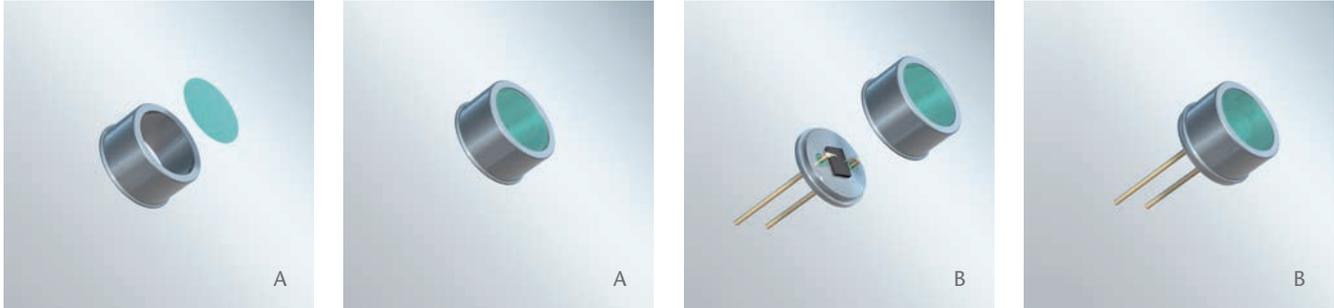
Glass-to-Metal Sealing (GTMS)

Data | Telecom

Whenever more digital information needs to be transmitted, opto-electronics are used more often than purely electronic solutions. Opto-electronics link the electrical with the optical world, for instance, by using laser diodes or photo sensors that convert electrical signals into light or vice versa. The boom in opto-electronics is accompanied by an increase in the demand for hermetically sealed packaging. These require not only glass feedthroughs for electrical conductors, but also optical interfaces such as windows, filters, lenses or glass fibers that allow for light to be guided through them in a defined manner.

TO Headers

Transistor Outline (TO) housings are the industry standard in opto-electronics. For decades, they have been used to package semiconductor chips and are available in standard sizes. These chips are used as transmitters or receivers of light signals and are reliably protected by the TO housings. Micro-electromechanical systems (MEMS), such as moveable mirrors for projectors, may also be assembled in housings that are similar to standard TO housings. TO housings generally consist of a round base with glass-to-metal feedthroughs that allow electrical signals to enter into the housing. Customers then add their (optoelectronic) components to the base and seal the package with a cap.



TO Opto-Cap
 A | SCHOTT Product
 B | Customer Assembly

Glass-to-Metal Sealing (GTMS)

Opto Caps

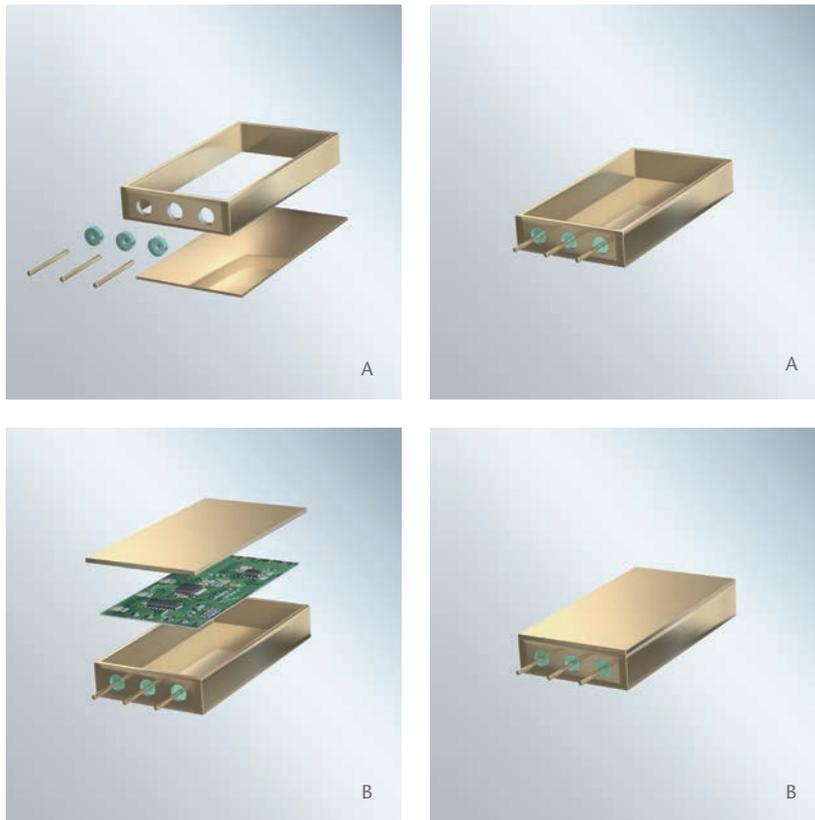
SCHOTT offers these caps with sealed-in lenses or windows in a wide variety of different types. With standard applications, such as photo diodes in motion sensors or infrared thermometers, the lens is simply melted into the window. If higher precision is required, for example for rapid data transmission or for CCD sensors in digital cameras, precision lenses or windows with special filter characteristics are used. These lenses or windows are soldered into the cap with glass solder under clean room conditions.

For datacom applications with very high data rates up to 28 Gbit/s, SCHOTT manufactures TO PLUS® headers and matching caps that offer extremely low losses at high frequencies.

As a result, network operators can upgrade their fiber optic networks to accommodate higher data rates by simply replacing older TO components with new ones.



Direct seal and solder glass sealed caps



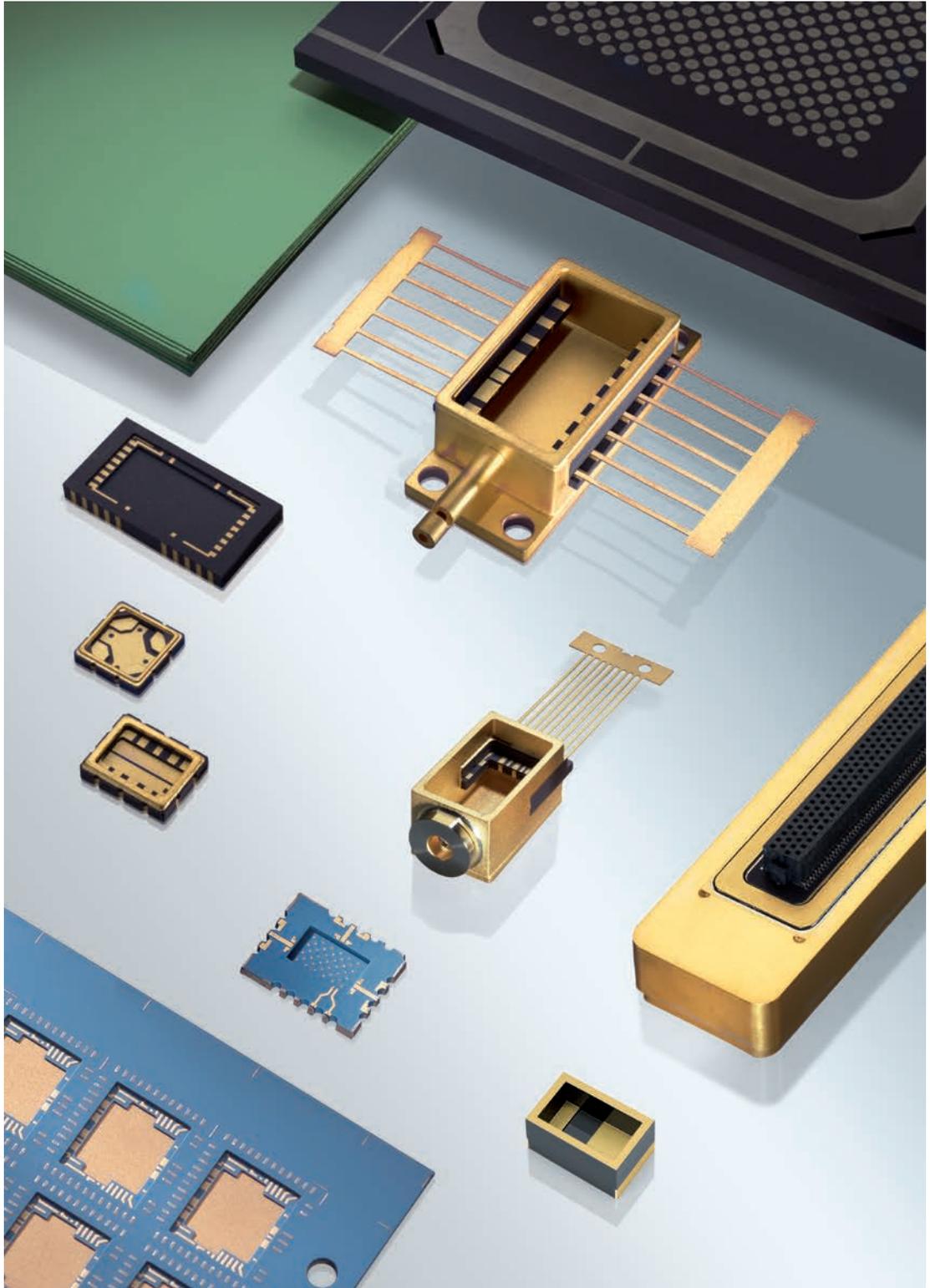
Hybrid package
 A | SCHOTT Product
 B | Customer Assembly

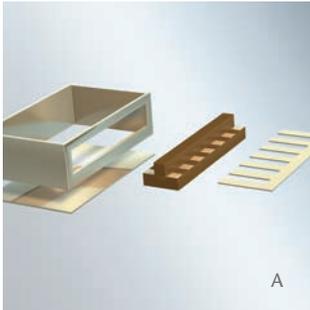
Glass-to-Metal Sealing (GTMS)

Microelectronic Packages | Hybrid Housings with GTMS

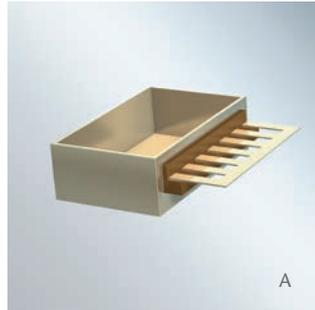
SCHOTT offers hybrid housings for highly demanding applications, such as if several complex opto-electronic components are to be combined with a large number of electrical and optical connections. These can contain lasers, for example, sensors for medical applications or microwave transmitters and receivers. Hybrid housings utilize the proven concept of glass-to-metal feedthroughs with sintered glass rings that are melted into the metal housing.

The possibilities of combining a series of functionalities within a single housing are therefore much greater. In addition to electrical interfaces for conducting current, voltages and high frequency signals, optical interfaces are possible in the form of windows and lenses – also in array form. Furthermore, heat sinks made of highly heat conductive materials, such as copper (Cu), coppertungsten (CuW) or copper molybdenum (CuMo), are used as thermal interfaces. Customers' individual applications and ideas and the complexity of hybrid housings are virtually unlimited. For this reason, SCHOTT always develops each hybrid housing in close cooperation with its customers. Ceramic-to-metal feedthroughs are another highly efficient technology for hybrid packages with high data transmission rates and low attenuation losses. These are explained in the section that follows.

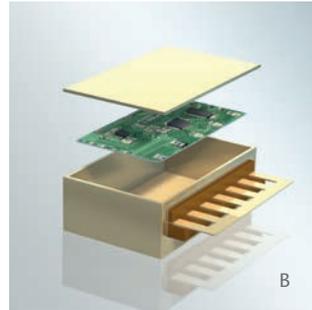




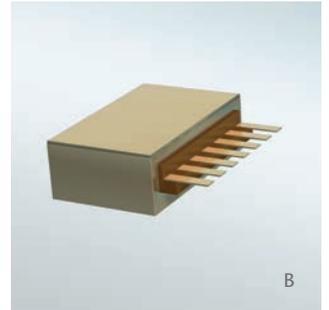
A



A



B



B

Ceramic-to-Metal Sealed
Microelectronic Package
A | SCHOTT Product
B | Customer Assembly

Ceramic-to-Metal Sealing (CerTMS®)

Microelectronic Package with CerTMS® enable high speed data transmission with a minimized footprint

The most important applications for ceramic-to-metal feedthroughs are:

- Opto-electronics
- Microwave components
- Lasers
- MEMS (e.g. mirrors for optical switches)
- Medical equipment
- Sensors
- Power electronics

As a result of increasing requirements in communication technology with the boom in opto electronics and the trend toward ever higher data transmission rates, glass-to-metal packages do not always offer the perfect solution. The possibilities of glass feedthroughs are limited when complex guidance of conductor paths to the inside of increasingly miniaturized packages is required. In this case, the use of multilayer ceramics (H/LTCC, High/Low Temperature Cofired Ceramic) offers significant advantages.

To meet these demands, SCHOTT provides small metal packages with an optical interface and one HTCC ceramic feedthrough per long side, for example. The electrical layout of these ceramic feedthroughs is widely variable, and coplanar. High frequency feedthroughs enable high data transmission rates of more than 40 gigabits/second. A typical package is the „butterfly package“, which is named as such because it resembles a butterfly.

However, significantly more complex configurations are now possible, such as hybrid solutions, in which some of the conductor paths are lead through ceramic into the package, while others are realized via glass-to-metal feedthroughs. Additional optical and thermal interfaces – especially for fiber optic applications – can be integrated using conventional soldering processes with glass or metal solder. It is important to understand, that the H/LTCC ceramic component of a hybrid package is not only a simple straight feed through for electrical signals, but it is also a part of the layout of the PCB (Printed Circuit Board) inside the package. For example, if H/LTCC ceramics are used for the base of the package, this may allow the full replacement of a stack of the kovar (or CuW) base and organic PCB, as well as the miniaturization of the entire assembly.

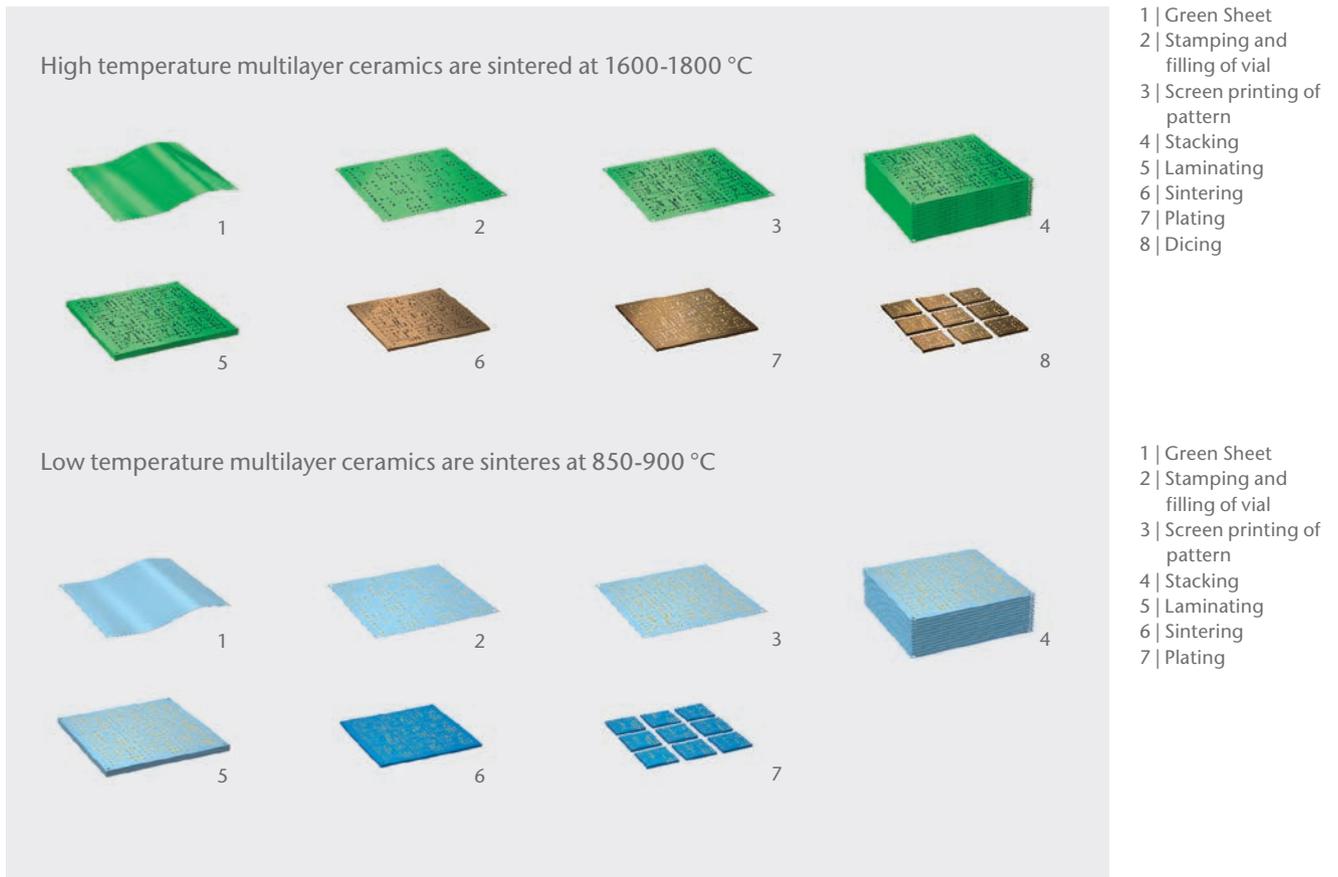


Ceramic-to-Metal Sealing (CerTMS®)

Manufacturing HTCC / LTCC Ceramics

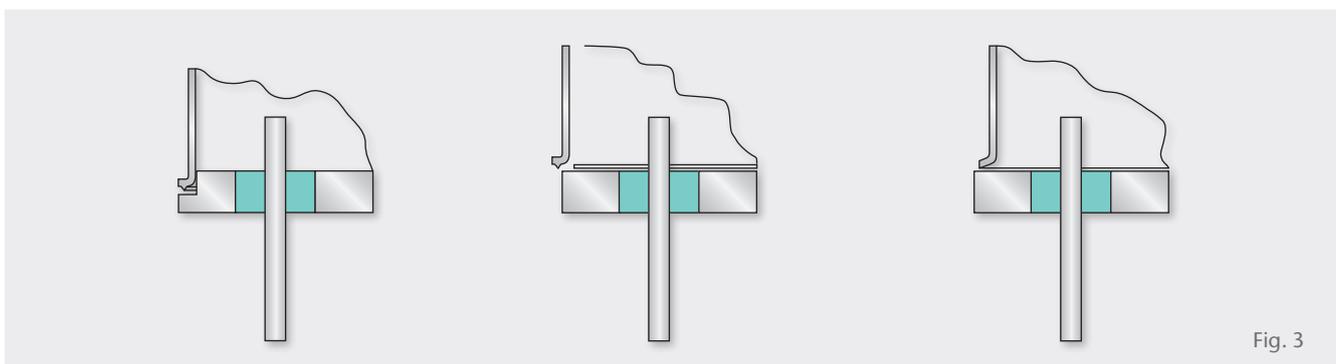
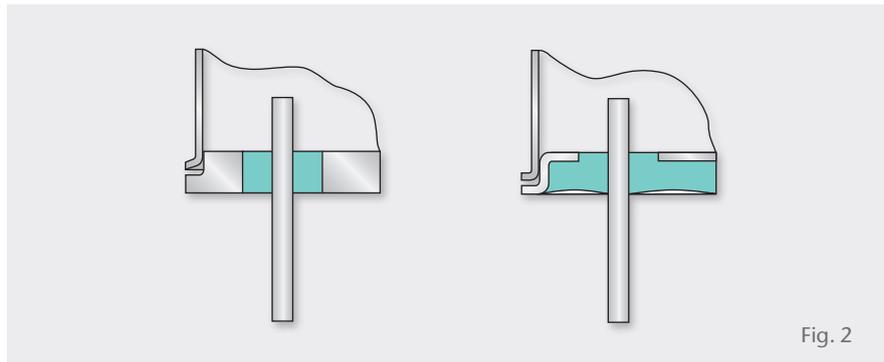
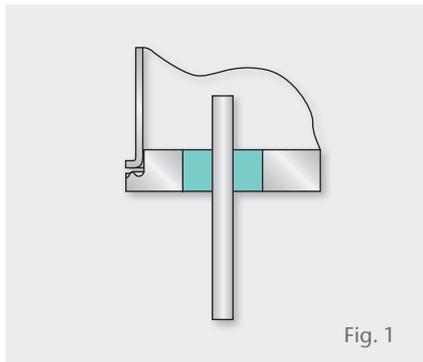
The basic raw material used to manufacture multilayer ceramic feedthroughs is aluminum oxide powder (Al_2O_3), which is mixed with a small amount of glass powder and a special organic binder. This slurry is poured onto a film strip and dried. The resulting green sheet has thicknesses of 100-500 μm . Using punching processes and silk screen printing, the sheet can be equipped with metallic lines and vias, laterally structured, stacked, and laminated, under high pressure forming a multilayer structure. This stacking at the end produces a three dimensional object that can contain a highly complex electrical wiring scheme in its interior.

During the subsequent co-firing process at temperatures of approx. 1600 °C (for HTCC ceramics with an alumina content of >92%), the binder evaporates and the powder mix sinters together with the structured metallizations into an extremely



dense and hard ceramic. Finally, plating and soldering processes are used to integrate the multilayer ceramic into a metal package and to create solderable and bondable interfaces outside and inside the hybrid package.

In addition to HTCC packages, the SCHOTT CerTMS® product portfolio includes feedthroughs and packages made of LTCC. In contrast to HTCC ceramics LTCCs are made of 50% aluminum oxide and 50% glass powders and are fired at a temperature of only approximately 900 °C. The low sintering temperature allows the use of gold and silver pastes, which exhibit very high electrical conductivity, for the conductor paths. This is essential for the transmittance of extremely high-frequency electrical signals. In addition, passive components, such as resistors, inductors or capacitors, can be integrated into this LTCC ceramic.



Welding ridges on bases (Fig.1) or caps (Fig.3) and slanted caps (Fig.2, Fig.3) are preconditions for hermetic housing seals.

The following techniques are mainly used to hermetically connect the feedthrough base with a cap or a cover:

- Electrical resistance welding
- electrode welding or
- rolled seam welding (wheel-to-base, wheel-to-wheel)
- Laser welding
- Soldering

In addition, there are sealing methods that do not incur a (local) temperature increase:

- Cold welding
- Crimp connection

Package Closing Technologies

Hermetically tight packages for electronic components usually consist of a base with hermetically tight feedthroughs and a cap to create a cavity for the component. As a rule, SCHOTT customers connect in-house the electronic component to the contacts of the base and weld or solder the cover. Use of the proper closure process is critical to ensuring that the package remains hermetically sealed.

Electrical Resistance Welding

The base and cap are put together during electrical resistance welding. Two electrodes on opposite sides conduct current through both components, which liquefies these at the corresponding point (i.e. welding ridges, slanted edges) and, thus, connects them. In doing so, the exact fit design of the base and cap is essential to achieving a hermetically tight package closure. Following the same principle, a variation of the sealing technique is used for hybrid packages where the material is fused point-by-point using rollers instead of electrodes during rolled seam welding.

Continuous further movement of the roller produces closed seams. In the case of metal packages, electrical current flows through the package and roller. However, this wheel-to-base process can only be used with bases made from electrically conductive materials.

For example, additional steps are often necessary with ceramic packages. Normally, in this case, metallic frames are first soldered to the ceramic components, which then are connected to a flat cover via rolled seam welding (wheel-to-wheel process). During this process, electrical current flows between the rollers through the conductive metal cover and fuses the components.

Laser Welding

Laser welding enables precise connection of very thin, delicate workpieces. In doing so, the laser focuses on a specific point on the workpiece surface, which then rapidly melts and connects both components as long as they are in direct contact with each other. However, this process cannot be used with components coated with gold, chemically deposited nickel (phosphor-Ni) or silver, as due to the surface reflection the energy is unable to penetrate the component.

Soldering

Soldering can also be used to connect the cap with a feedthrough. Use of the correct soldering temperature is critical to avoid damaging the feedthrough. Matched seals should be soldered at up to 400 °C maximum and compression seals at only up to 260 °C maximum. For soldering, the component surfaces must be wettable, and without a thick gold coating for tin-based solders, as otherwise tin embrittlement may result.

Cold Welding

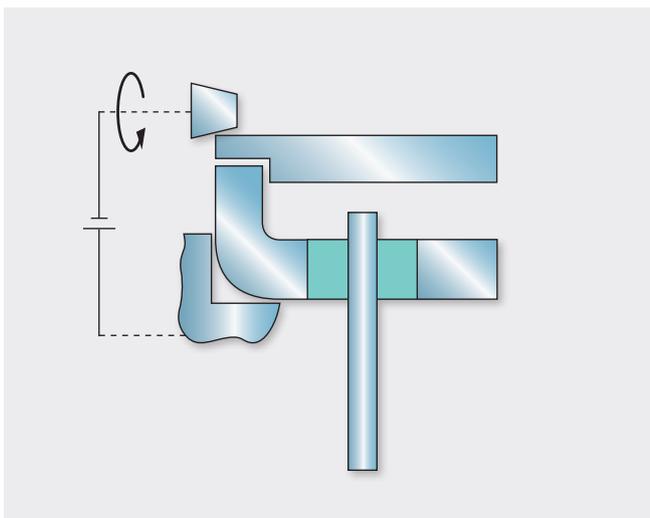
Pressure applied to the surfaces to be connected at room temperature results in cold welding, usually in the form of ring welding. During this process, high quality contact surfaces ensure good contact between both interface surfaces. This method is frequently used for crystal resonator packages. For cold welding, surfaces must be clean, very flat and parallel. The pressure level and tooling design are additional key parameters.

Crimp Connection

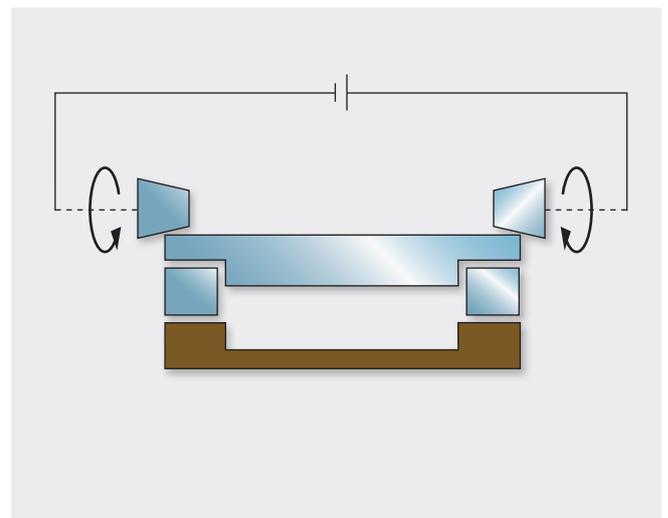
With this technique that is based on a principle similar to cold welding, the base and cap surfaces are coated with solder or a similar soft metal. Compression of the components then produces a fitted seal. This sealing method is primarily used to hermetically package clock quartzes.

Careful Adjustment of Process Parameters Required

All sealing technologies require careful adjustment of process parameters, such as contact pressure and energy. This is because excessively high welding currents, electrode or roller pressure, or laser energy can damage the feedthrough. If welding currents, electrode or roller pressure, or laser energy are too low, defective welding joints can result. In the case of electrode welding, non-parallel electrodes can also impair the leak-tightness of the feedthrough or weld. SCHOTT not only provides technical advice to customers in helping them to select suitable sealing processes and compatible surfaces, but also tests specific sealing and surface technologies for customers at SCHOTT's own applications laboratories.



Wheel-to-base process



Wheel-to-wheel process

Materials Data

The following tables describe the materials and properties of the most common glass-to-metal seals and ceramic seals.

Material	Designation according to DIN	Material no. DIN	Main components [%]	α 20-300 [$10^{-6}K^{-1}$]	Electric resistivity at 20 °C [$\Omega mm^2/m$]	Density [g/cm^3]	Curie temp. [°C]
NiFeCo, Kovar	NiCo 2918	1.3981	29 Ni 18 Co Rest Fe	5,4	0,48	8,3	approx. 425
NiFe, Alloy 52	NiFe 47	2.4475	51 Ni Rest Fe	10,2	0,38	8,2	approx. 495
NiFe	NiFe 45	2.4472	54 Ni Rest Fe	11,4	0,35	8,2	approx. 525
Construction steel (CRS)	St..... C..... Ck.....	1.02.. – 1.03.. 1.11..	Fe	ca. 13,0	ca. 0,10	7,8	–
Rust and acid proof steels - ferritic - (SS)	X..Cr..	1.40.. – 1.41..	Cr 12 – 19 Fe	ca. 11,0	0,55 – 0,70	7,7	–
Rust and acid proof steels - austenitic - (SS)	X..CrNi..	1.43.. – 1.45..	Cr 16 – 28 Ni 4 – 26 Fe	ca. 17,0	0,60 – 0,90	7,7 – 8,0	–

Sealing metals

Material	Composition	Dielectric constant ϵ at 1 MHz/10 GHz	Loss $\tan \delta$ ($\times 10^*$) at 1 MHz/10 GHz	Thermal Conductivity [W/mK]	Coefficient of Thermal Expansion [ppm/K]	Flexural Strength [MPa]	Density [g/cm^3]	Feed-through materials	Min. lines/spaces (Thick Film Technology) [μm]
HTCC	>92% Al_2O_3	9,4/9,0	5/10	17	6,8	460	3,6	W, Mo	100/100
LTCC*	~ 50% Al_2O_3 ~ 50% glass	7 - 8	10/10 - 50	2,8 - 5	5 - 6	250 - 320	2,8	Au, Ag, AgPd, AuPt, AuPtPd	50/50

Ceramic seals

* Variations of physical properties are due to different green sheet materials from various suppliers

1	2	3	4	5		6	7	8		9		10		
Glass no.	Main applications	α_{20-300}	Transformation temperature T_g [°C]	Glass temperature in °C at viscosities dPas		Density [g/cm ³]	t_{k100} [°C]	log of the electric volume-resistivity in Ω cm at		Dielectric properties at 25 °C for 1 MHz		Chemical resistance classes		
		[10 ⁻⁶ ·1/K]		10 ^{7,6}	10 ⁴			250 °C	350 °C	DZ	tan δ [10 ⁻⁴]	W	S	L
8242	Matched seals with NiCo 29 18 o. NiFe 42	4,8	470	720	1120	2,27	302	8,9	7,2	4,9	26	3	4	3
8250	Matched seals with NiCo 29 18 o. NiFe 42	5,0	492	715	1060	2,28	384	10,3	8,5	4,9	22	3	4	3
8350	Compression seals Seals with steels and NiFe alloys	9,0	520	708	1035	2,52	198	7,1	5,7	7,2	70	3	1	2
8421	Compression seals Seals with steels and NiFe alloys	9,6	525	721	1000	2,59	253	8,1	6,4	7,4	43	3	3	2
8422	Compression seals Seals with steels and NiFe alloys	8,6	540	722	1027	2,46	212	7,3	5,8	7,3	60	2	3	3
8537	Battery seals Seals with steels and NiFe alloys	9,1	480	595	745	2,75	395	10,7	8,7	7,1	10	5	4	3
8629	Compression seals Seals with steels and NiCo 29 18	7,6	529	720	1020	2,52	267	8,3	6,7	6,4	26	1	3	2
8630	Compression seals Seals with steels and NiFe alloys, increased requirements for electrolytic resistance and temperature stability	9,1	440	660	975	2,53	317	9,3	7,6	6,5	21	3	1/2	2

Sealing glasses for Glass-to-metal seals, *Manufactured by SCHOTT North America, Inc.

The sealing metals indicated in **column 2** are further described in the “Sealing metals” table on page 27. The mean linear coefficient of expansion in the temperature range 20 to 300 °C according to DIN 52 328 is shown in **column 3**. The transformation temperature according to DIN 52 324 is shown in **column 4**. **Column 5** shows viscosity temperatures marking the following processing stages: 10^{7,6} dPas (softening temperature): Noticeable deformation of glasses under their own weight, even after short heating periods (minutes). 10⁴ dPas (processing temperature): Central viscosity of the range from 10³ to 10⁵ dPas in which most processing techniques such as pressing, blowing and drawing are applied. **Column 7** shows the temperature at which the electrical resistivity is 10⁸ Ohm cm according to DIN 52 326. In **column 9** “DZ” stands for “Dielectric constant” and “tan” for “Dissipation factor”. Detailed chemical resistance data for our main glasses is indicated in **column 10**. Resistance to water (W) according to DIN ISO 719 is subdivided into five resistance classes. The higher the class number, the lower the resistance. Resistance to acid (S) according to DIN 12 116 is subdivided into four classes and the resistance to alkaline solutions (L) according to DIN ISO 695 is subdivided into three classes.



Quality Assurance

SCHOTT Electronic Packaging maintains a comprehensive quality management system that has been certified according to DIN EN 9001 since 1992. ISO TS 16949 (analogous to QS 9000/VDA 6.1) applies for the automobile industry.

The quality management system is continuously monitored and adapted to meet new requirements. The high quality standard at SCHOTT covers all manufacturing steps and is strictly controlled. In doing so, SCHOTT primarily utilizes statistical process control on a random sample basis. Quality test results are recorded and evaluated in a modern CAQ (Computer Aided Quality) system and are used for continuous quality improvement.

The quality benchmarks for SCHOTT products are always our customers' requirements. Working closely with our customers, we agree on quality requirements, such as exact selection of key, quality-impacting characteristics, test types and measurement value limits that are to be met, etc. This agreement is documented in a technical product specification.

The following standard tests are used at SCHOTT to monitor the quality of glass-to-metal feedthroughs:

- Dimensional and visual inspection
- Electrical insulation resistance
- Hermeticity
- Layer thickness of galvanic surfaces
- Surface adhesion



Various standards are applied during the tests. In doing so, SCHOTT always complies with the most stringent standards; for glass-to-metal feedthroughs for microelectronics, SCHOTT complies primarily with US military standards. SCHOTT also complies with relevant IEC and EN standards. For environmental testing, the most important standard used is MIL-STD-883 "Test Methods for Standard Microcircuits". Additionally, the DIN EN 60068 test standard series can also be agreed upon.

The SCHOTT plant in Landshut, as well as the accredited test laboratories at SCHOTT's headquarters in Mainz (Germany), are equipped to perform all established quality measurements. Specific special test procedures, for example for shock, vibration and acceleration tests, are contracted out to external test laboratories.

SCHOTT Electronic Packaging ensures even during the design phase its products comply with current environmental standards. This is why SCHOTT is certified according to ISO 14001. SCHOTT also complies with the requirements of international directives, such as 2002/95/EC (Restriction of Hazardous Substances Directive (RoHS)).

In addition to these standard tests, SCHOTT also offers a wide range of special tests:

- Tension and compression tests
- Bend and pull tests
- Solderability tests
- Thermal shock tests (liquid/liquid)
- Thermal shock tests (air/air)
- Corrosion, e.g. salt spray tests
- Welding tests as capping tests etc.

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