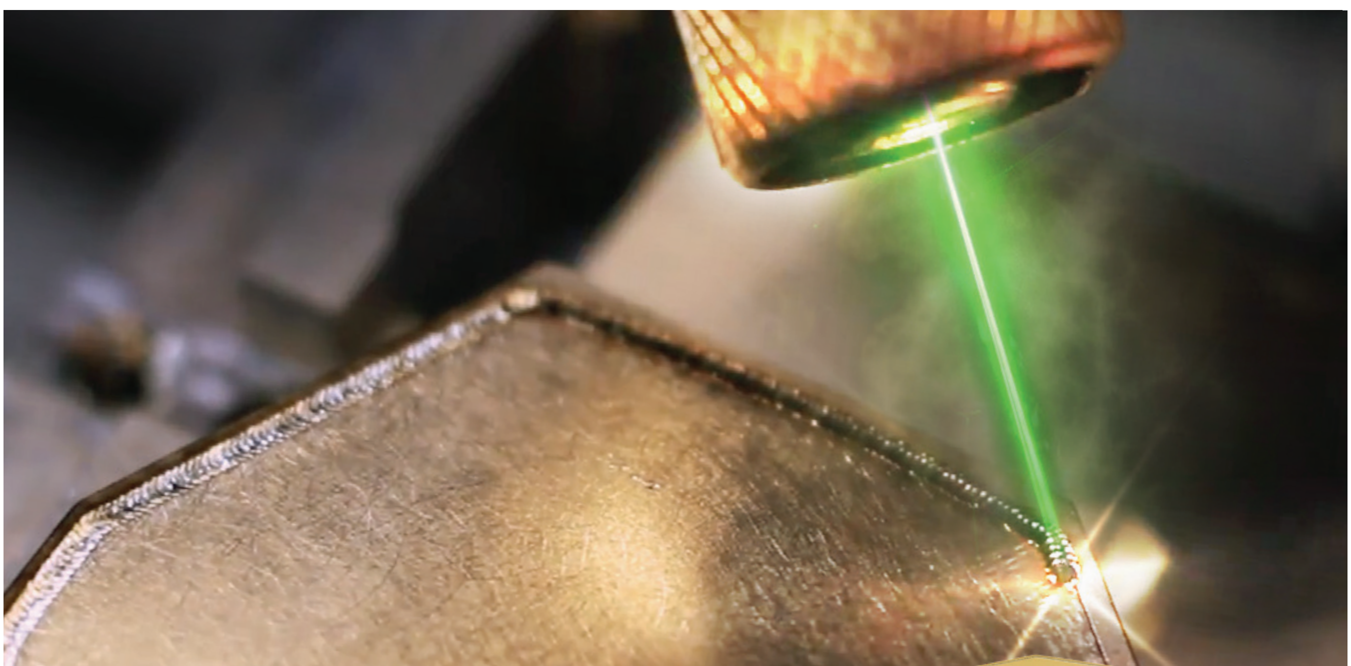
Tech Brief

5 Keys to Perfecting Laser Welded Hermetic Seals



INTRODUCTION

Hermetic seals are used throughout the high-tech industry to provide maximum packaged protection from environmental elements that can reduce the reliability and required lifetime of critical electronics. Laser welded (or laser fusion welded) hermetic seals are the certified method governed by many military and aerospace quality and reliability standards (MIL-STDs). Devices designed to (or near to) these standards, include those found in the space, aerospace, military, high-power, high-frequency, science/research, and medical device markets, where maintaining a near absolute barrier between the electronics and outside conditions is necessary. There are many types of hermetic seals and packaging materials a designer can choose from. Fusion welding hermetic seals with lasers has become the leading solution for applications that require complex, mixed material, and/or precise and fast sealing.

Though fusion welding can be performed by a variety of means, laser fusion welding your hermetic seals offers the most confidence and a variety of benefits. These include: tighter tolerances, three different joint-type options, and flexibility that can enable new geometries and material use. This technical brief provides five keys to consider when hermetic sealing via laser welding.

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I. Evaluate Your Package and Plating Material Options

As laser welding is typically an autogenous welding process, only the materials of the lid and enclosure are part of the weld. This means that the exact material matchup of the lid/enclosure materials is critical, along with any intermetallics, cooling rate matchups, reflectivity and plating. Laser welding also has a small heat affected zone (HAZ) and imparts minimal heat to the material, so cooling tends to happen quickly. This can be a factor with some types of metals and combinations of metals, as it could impact weld quality and yields. So, gaining a basic understanding of various material properties and their interaction with laser energy is an important first step in ensuring quality seals.

Most metals, and even mixed metals can be laser welded. Some alloys and metal combinations are not compatible with laser welding without filler materials, and some combinations and alloys cannot be laser welded reliably for hermetic seals. The exact geometries, materials, and weld type determine the exact amount of laser energy and exposure necessary to produce reliable welds.

Table 1: Package and Plating Material Options for Hi-Rel Devices				
Package Materials	**Benefits**	**Considerations**	**Best Suited for Laser Welding**	**Special Cases**
Aluminum	Lightweight Good corrosion resistance Good heat dissipation Mechanically strong Relatively low-cost enclosure	High reflectivity High conductivity Requires high-peak power pulse		Aluminum type 6XXX, 7075, and Alloy 2219 cannot self-weld and require filler material (Alloy 4047)
Kovar	CTE match with Glass and Ceramics Good corrosion resistance if plated. Ease of machining and drawing Few metallurgical problems compared to Aluminum.	Kovar is often plated, so the plating specifications and materials must be considered Denser than Aluminum, so may be limited by weight constraints	✓	
Iron Nickel Alloys / Invar	Ferromagnetic properties Good electrical conductivity Sometimes used in the place of Brass Similar welding characteristics to Kovar Invar has near zero CTE around room temperature	Often plated, so plating specifications and materials must be considered	✓	
Stainless Steel	Mechanically robust Excellent corrosion resistance Good metallurgical characteristics for hermeticity Austenitic stainless steels with nickel content exhibit laser welding benefits	Much heavier than Aluminum More difficult to machine than Aluminum More expensive than Aluminum	✓	Certain compositions of 304L have been known to crack during laser welding High posphorous and/or sulfer compositions, like those used for free machining steels (AISI-303) may hot crack during laser welding 400 series ferritic alloys may yield martensitic formations in the weld zone, though preheating can mitigate some martensite formation
Titanium	Biocompatible with humans Good laser welding compatibility Mechanically strong	Must be laser welded with Argon or Helium to prevent oxidation, not Nitrogen.	✓	
Copper Alloys	Non-magnetic High electrical and thermal conductivity	High reflectivity and thermal conductivity make welding difficult to depths beyond 0.5 mm		Beryllium copper and nickel plated copper may perform better than pure copper, though beryllium copper can produce toxic beryllium oxide during machining Copper tungsten and copper nickel alloys tend to weld well Copper-Zinc/Brass alloys weld poorly a zinc vaporize near the melting temperature of other metals in the alloys. Can be laser welded if techniques prevent out-gasing from reducing weld quality
Precious Metals: Platinum, Silver, and Gold	Excellent corrosion resistance Excellent electrical conductivity	High reflectivity and thermal conductivity make precious metals difficult to weld depths beyond 0.5 mm.		
Plating Materials	**Benefits**	**Considerations**	**Best Suited for Laser Welding**	**Special Cases**
Electrolytic Nickel	Excellent corrosion resistance Good electrical conductivity	High reflectivity and thermal conductivity make welding difficult to depths beyond 0.5 mm	✓	
Kovar	Excellent corrosion resistance Good electrical conductivity	High reflectivity and thermal conductivity make welding difficult to depths beyond 0.5 mm		
Iron Nickel Alloys / Invar	Excellent corrosion resistance Good electrical conductivity	High reflectivity and thermal conductivity make welding difficult to depths beyond 0.5 mm	✓	
Tin and Zinc	Excellent corrosion resistance Good electrical conductivity	High reflectivity and thermal conductivity make welding difficult to depths beyond 0.5 mm		

A. Plating Considerations

Plating of electronic components and metals used for hermetic enclosures is common when corrosion, solderability, conductivity, thermal management, and other process concerns exist. This means that a laser welding process for hermetic sealing may need to be performed on one or more plated surfaces. Nickel and gold are the most common platings for electronics, though tin, silver, and copper plating are also used.

Nickel Plating

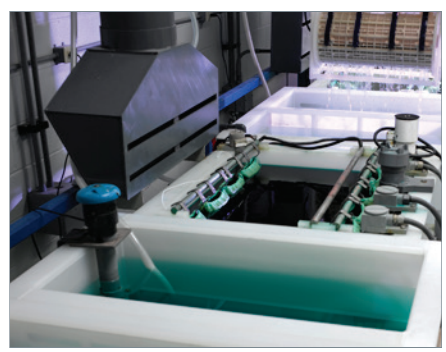
Nickel plating is either applied with an electrolytic (i.e. electroplating) or electroless process. But when there's a choice, designers should choose electrolytic over electroless. The reason is an electroless nickel plating process has a tendency to create intermetallic changes, porosity, and cracking during laser welding due to the phosphorus content added during the plating process.

Gold Plating

In addition to electrolytic plated nickel, gold plating (common when working with Kovar) is an acceptable preparation step. (Review **Table 1** for additional details.) Gold plated mild steel however, is not. It can form intermetallic segregation within the laser weld. This is especially problematic for hermetic seals.

Tin and Zinc Plating

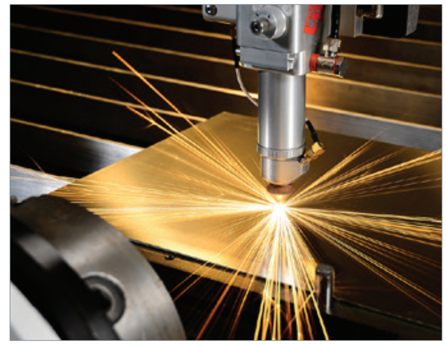
Though there is substantial effort to develop methods to enable high quality laser welding of galvanized steel to accommodate the automotive industry, among other industries.



Electroplating
Electrolytic plating of nickel is preferred over electroless plating.

II. Understand Your Laser Options

There are three main types of laser technologies used for creating fusion welded hermetic seals: CO_2, diode, and Nd: YAG. Lasers can be used in either continuous wave (CW) or pulsed modes. Also, there are various methods of beam delivery, including fiber optic, of which a variety of crystals or diodes, including Nd:YAG, can be used to generate the laser. An important note is that each type of laser, beam delivery, and laser welding machine design exhibits different properties and performance based on laser frequency, power, duty cycle, and material properties.

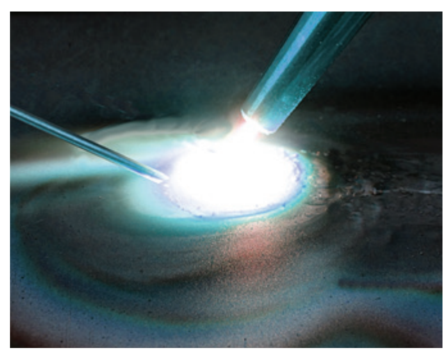


Laser Technology and Materials
While CO_2, diode, and ND: YAG lasers can be used to laser weld, the best technology depends on the materials being processed.

For many designers, the exact type of laser being used for the weld is only a concern as far as material choices. Most designers won't have a range of laser technologies to choose in-house, and will instead rely on a laser service job shop with technicians who are well-experienced and skilled in state-of-the-art laser technologies. These technicians are able to provide more detailed insights into the exact laser type, machine, and process necessary to provide high-quality welds for a designer's specific application. As every hermetic enclosure has its own unique stackup of considerations, working with a well-established laser service organization with skilled technicians is a sound decision, from a cost and yield perspective.

III. Decide on Your Joint Type

There are three main joint types to consider when laser welding; butt, lap, and fillet joints. Common amongst laser weld joints are the tolerance and spacing constraints between the joints. Generally, the tolerances for hermetic sealing is very tight. As a laser beam kerf width is typically on the order of a quarter of a millimeter, or a hundredth of an inch, and the weld puddle is proportionally narrow, to meet quality and reliability standards, a high-power laser seal weld is optimal for hermetic seals. An early consideration to keep in mind, however, is that the weld puddle during laser welding needs to be about 85% to 90% wider then the kerf.



Welding Puddle
Different from a laser's kerf, or beam width, a laser's action naturally creates a "puddle", which will be 85% to 90% wider.

A. Butt Joint

A butt joint is where two workpieces are physically touching ("butted" together) with a very narrow gap that is typically on the order of one hundred microns. Tolerances of the gap, material thickness, and edges must be very small to ensure a smooth bead along the seam. Given the sub-millimeter beam width of a laser weld, butt joint gaps must be substantially less than the beam width, and the lip of the cover must be larger than the beam width. However, a technique known as beam wobble can be used to loosen this constraint somewhat. A general guideline for butt joints is that the gap between the lid and enclosure cannot exceed 10% of the thinnest material thickness or of the penetration depth, whichever is less.

Key Characteristics

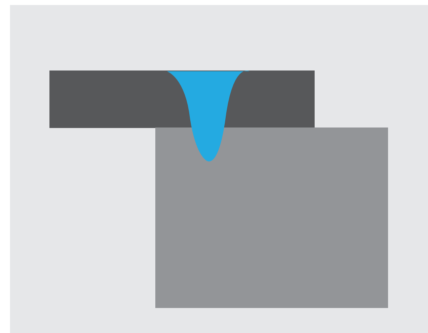
- No filler material needed, and less material at the joint
- Faster laser speeds or less laser power can be used
- Small heat affected zone (HAZ) with minimal heating and distortion
- No step or fixturing requirements
- Does require tight tolerances of lip and edges and precise fit-up can be challenging
- Weld strength is related to weld depth
- Thinner materials increase tolerance constraints

A laser welded butt joint is considered extremely efficient, as the energy from the laser is solely focused along the joint line and can be done in a single pass. Mechanically, butt welds are reasonably strong and can be made to a minimum strength of the weld materials. This type of weld is used with larger enclosures and assemblies, and generally doesn't require any additional tooling to hold the enclosure lid in place.

Butt Joint
A general guideline for butt joints is that the gap between the lid and enclosure cannot exceed 10% of the thinnest material thickness or of the penetration depth, whichever is less.

B. Lap Joint

A lap weld is performed when a relatively thin layer of the material overlaps the other side of the joint, and requires the weld to be done through the top thin layer of material. This method is commonly used when welding sheet materials, or a thin sheet to an enclosure. The tolerances for this type of weld are less stringent than for a butt weld, though tooling is required to ensure that the overlap is aligned.



Lap Joint
This type of joint is used when materials overlap, and when aesthetics are important.

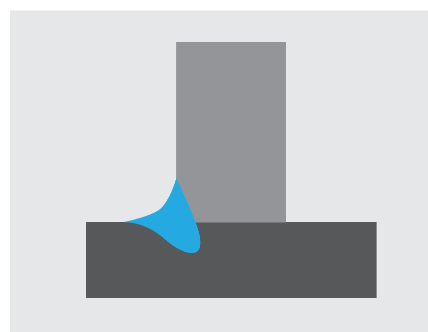
Key Characteristics

- Larger process window than butt joint, less stringent lip tolerances
- Requires fixturing and lineup
- Greater laser energy required or slower processing with more heating and potential distortion
- Less efficient than butt joint
- Limits on the thickness of the top layer material based on laser power
- Weld strength derived from weld thickness at interference

A general guideline suggests that the gap must not exceed 20% of the thinnest material thickness or of the penetration depth, whichever is less. As a lap weld requires penetration of the top material, greater laser energies are required to first penetrate and then weld the joint beneath the top material. There is also a limit to the thickness of the top layer of a lap weld, and this constraint depends on the laser energy and penetration power of the laser for a given top layer material.

C. Fillet Joint

A fillet joint is similar to a butt joint, but performed on parts butted at a 90° angle. The joint is done at the edge of where the material meets at one side of the joint, with the laser energy coming at an angle or from top-down. A fillet joint is almost as efficient, considering laser power to weld strength, as a butt joint. A fillet joint is commonly used in electronic sealing, and generally requires tooling to ensure the material meets at an appropriate angle and with adequate tolerances. Generally, a fillet joint gap can be reliably performed as long as the gap doesn't exceed 15% of the thinnest material thickness or penetration depth, whichever is less.



Fillet Joint
FIllet joints are similar in strength and durability to butt joints, but are used when materials butt at a 90° angle.

Key Characteristics

- Efficient laser power and exposure time to weld joint strength
- More forgiving fit-up than butt joint, but less than lap joint
- Requires angled laser or fixtured parts at an angle

IV. Consider Final Testing and Potential Rework in Advance

Final testing stages of a hermetically sealed device are necessarily stringent in order to ensure they are application-ready for extended use in harsh environments. As such, even the most visually perfect seal can fail, resulting in removal of the lid, device re-inspection, and re-sealing it. As this is not uncommon, additional overhead and delivery time must be factored in for rework that includes micro-machining of the enclosure to overcome subtle geometric changes to the top of enclosure walls as a result of laser de-lidding. If this is not inspected for and adjusted, the result is poor matchup and future failed tests and rework once again.

The testing and rework stages are determined by the qualifications and certifications necessary to meet with standards associated with the application. For military and space (NASA) applications, a helium leak test (MIL-STD-883 Test Method 1014 for hybrids/microcircuits and MIL-STD-750 Method 1071 for discrete semiconductor devices) is performed to determine the quality of the hermiticity. If found inadequate, a laser welded lid can be removed safely via precision laser cutting. Then the laser welding process is repeated for the seal after the initial cleaning, baking, and fixturing steps are performed.

MIL-STD-750 E, Test Method 1071.9 "Hermetic Seal"
(Equivalent standard leak rates (atm cc/s air) per volume)

- <= 0.002 cc is 5x10e-10
- > 0.002 and <= 0.05 cc: is 1x10e-9
- >0.02 and <= 0.5 cc: 5x10e-9
- >0.5 cc: 1x10e-8

MIL-STD-883H, Test Method 1014.13 "Seal"
(Equivalent standard leak rates (atm cc/s air) per volume)

- <= 0.01 cc: 5x10e-8
- > 0.01 and <= 0.5 cc: 1x10e-7
- > 0.5 cc: 1x10e-6

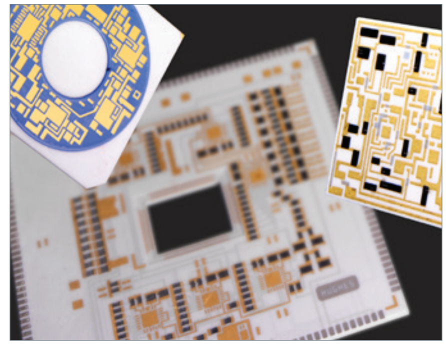
NASA and the U.S. Military are actively investigating the helium leak test effectiveness as a measure of hermiticity, and other hermiticity test methods may be required in the future.

Rework Considerations
As material is lost during de-lidding, there is likely to be poor matchup after cutting and the parts may require additional machining to be viable again for resealing.

V. Pre-prep Considerations

A. Substrates

While not necessarily impacted by the processing step of laser lidding, due to the fact that your devices will be deployed in critical, long-life applications, it's important that your ceramic base materials, or substrates, are pre-processed with precision lapping and or polishing to ensure proper flatness, camber, and parallelism. Poor flatness and parallelism of your ceramic material can lead to adhesion and trace/space inconsistencies during circuit metallization (and thus, poor yields), and can create variability in thermal conductivity and electrical insulation across the foundation of your device. Poor camber creates similar electro-mechanical challenges. All can turn into future de-lidding and rework.



Consider Substrate Prep
Poor flatness and parallelism of your ceramic material can lead to adhesion and trace/space inconsistencies during circuit metallization (and thus, poor yields), and can create variability in thermal conductivity and electrical insulation across the foundation of your device.

B. Gases

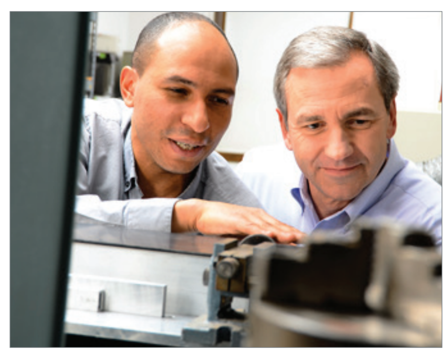
The inert gases (argon, nitrogen, or helium) used during laser welding depend on material compatibility.

C. Fixturing

Fixturing depends on the joint type and geometries of the enclosure being hermetically sealed. Many aspects, such as time, laser power, materials and pulse duration depend on these pre-prep decisions.

CONCLUSION

A laser welding process that produces high-quality, rapid, and low-cost welds can be performed on an extremely wide range of materials and geometries. Hence, laser welding has become one of the choice methods for hermetically sealing electronic packages/enclosures for the devices used in military, industrial, aerospace, space, medical, and microelectronic applications. Developing a suitable laser hermetic sealing process depends on many factors. Therefore, choosing an experienced laser service partner with a solid track record for hermetic sealing, is also a key decision in meeting and exceeding customer expectations for the reliability and longevity of your electronics.



Next Steps:
Request a Laser Welding Quote.

Learn more by downloading these pieces of related content: "The Advantages of Laser Welding Over Arc Welding" and "Pre-metallization Benefits of Lapping and Polishing Ceramic Substrates."

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