Closing the Gap: Overcoming Common Challenges in Laser Welding of Medical Devices

Laser welding is a key manufacturing process for medical device manufacturers, valued for its precision, speed, and ability to work with microscale components. From implantable electronics like pacemakers, to surgical tools and diagnostic devices, the need for repeatable, high-integrity welds continues to grow. But despite its advantages, laser welding is not immune to production challenges. Its precision is such that even very small changes in material quality, laser settings, or fixture alignment can result in defects that compromise strength, conductivity, and biocompatibility. This article explores four common issues encountered when laser welding metals and outlines actionable solutions for manufacturers aiming to improve reliability and reduce scrap.

UNDERSTANDING WHAT DRIVES WELD QUALITY

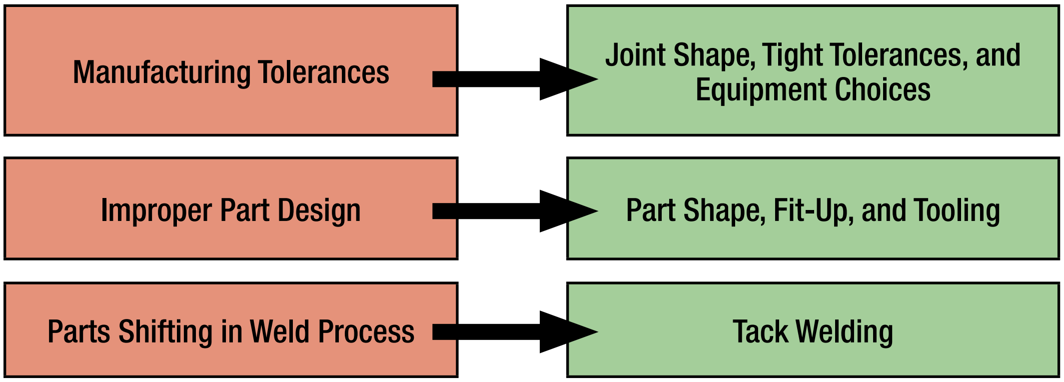
At its core, laser welding creates a bond by directing focused thermal energy onto a joint which melts and fuses the base metals. Most medical welds are shallow, precise, and executed on materials like stainless steel, titanium, and nickel alloys. Weld quality and success are shaped by three primary factors:

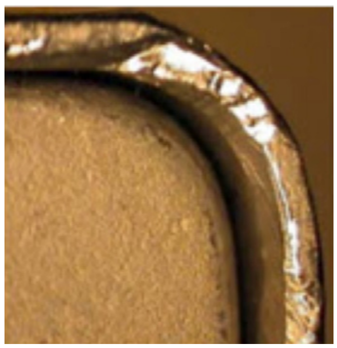
- Material properties: composition, reflectivity, coatings, and oxide layers
- Process parameters: peak power, pulse energy, pulse width, shielding gas, spot size, repetition rate, and weld speed
- Equipment: laser source, beam delivery, motion control, and part fixturing

By documenting and tightly controlling these variables as part of a validated weld recipe, manufacturers can reduce inconsistencies and boost first-pass yield. But even in well-controlled environments, variation can creep in. Monitoring key process values and understanding root causes is essential to keeping production on track. Let’s look at 4 common issues.

ISSUE #1: GAPS BETWEEN WELD SURFACES

Laser weld gaps may arise from factors such as poor part fit-up at the design stage, insufficient fixturing to hold components in place, variations in manufacturing methods and tolerances, or thermal distortion during processing. In the context of high-reliability medical devices, even minimal gaps (on the order of 10s to 100s of microns) can lead to incomplete fusion or underfilled joints—compromising both the structural integrity and functional performance of the weld. These imperfections may result in reduced mechanical strength, failure to create a hermetic seal, and inconsistent weld formation.





Gap

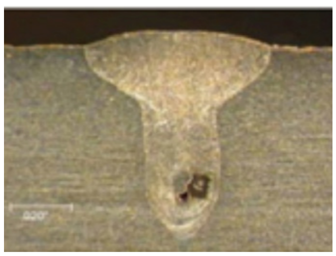
Prevent Gap

To address this issue, manufacturers should first concentrate on designing components with joint geometries that promote accurate alignment and fit-up. Pre-tacking with light welds can also help hold parts securely in place during the final welding process, reducing the chance of movement caused by thermal contraction. And using beam shaping techniques—such as laser wobble or oscillation—can help broaden the melt pool, allowing the weld to bridge small gaps and produce a more uniform, high-quality joint. Finally, and perhaps most obviously, manufacturing an appropriate fixture to hold the parts together during the welding process is key to achieving success.

ISSUE #2: POROSITY

Porosity in laser welds occurs when gas becomes trapped in the molten weld pool, creating voids as the material solidifies. This issue is often the result of inadequate shielding gas coverage, surface contamination, or the use of alloys prone to gas absorption during welding. It can also form due to suboptimal laser parameters. In medical device manufacturing, porosity can significantly impact product performance—reducing weld strength, causing failures in hermetic leak tests, and, most alarming, disrupting electrical conductivity in components where signal integrity is critical.

- Improper Gas and Coverage → Correct Gas and Flow Rate
- Contaminants and/or Metallurgy → Pure/Correct Laser Welding Material
- Inadequate Pre-Clean → Prepare and Clean the Material
- Unbalanced Laser Settings → Adjust Pulse Shape and Settings



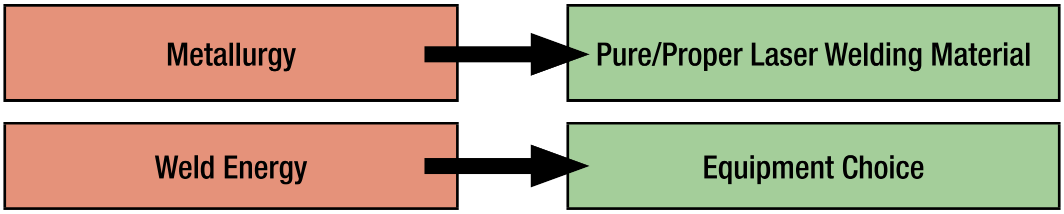
Porosity

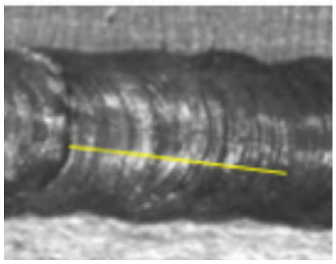
Prevent Porosity

To prevent porosity resulting from shielding gas irregularities, it's essential to maintain a laminar flow of argon or nitrogen and eliminate leaks or turbulence in the weld zone. Cleanliness is equally important; removing oils, oxides, and debris from part surfaces before welding can significantly reduce the risk of trapped gases. Selecting weld-friendly alloys—or using compatible filler materials—can help avoid porosity-prone chemistries and improve overall weld quality. And, finally, optimizing the balance between peak power and pulse width is critical to minimizing porosity. When peak power is set too high, rapid expansion and vaporization of the material can result in void formation during cooling. Employing pulse shaping strategies, such as incorporating a longer downslope, promotes smoother material flow and controlled solidification, thereby limiting porosity.

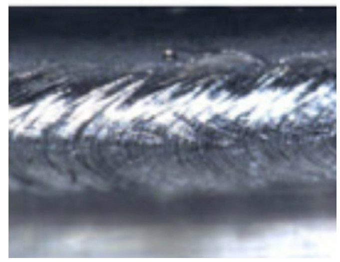
ISSUE #3: CRACKING

Cracks in laser welds are typically the result of internal stress that develops during the solidification phase of the weld. This issue is prevalent when welding high-carbon steels, certain aluminum alloys, or dissimilar metals with mismatched thermal properties. In medical devices, cracks can lead to joint failure under mechanical stress or fatigue, cause electrical disconnection in microelectronic assemblies, and result in visible cosmetic flaws in exposed areas of the product.





Cracking



Prevent Cracking

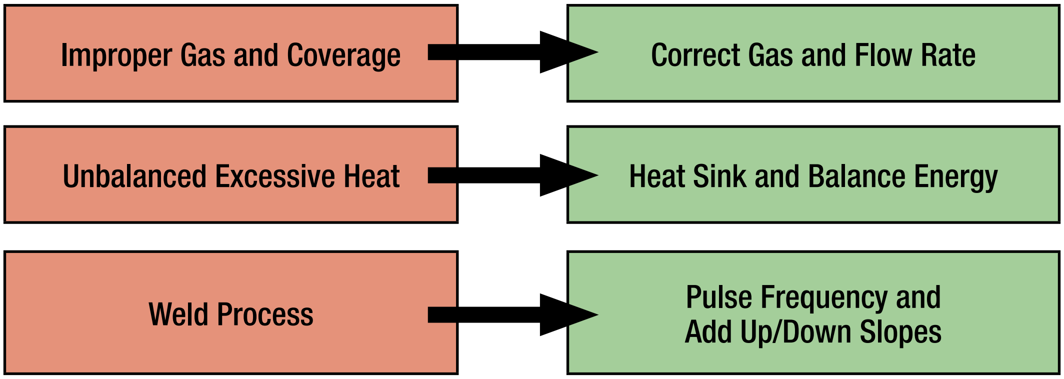
To minimize the risk of cracking, manufacturers should prioritize the use of weld-friendly materials—selecting alloys with proven weldability and lower susceptibility to thermal stress. Controlling the laser pulse shape is also critical; by adjusting upslope, downslope, and pulse width, it's possible to reduce the kinds of rapid thermal gradients that contribute to cracking. Similarly, employing a CW fiber laser can promote more uniform cooling, further lowering the likelihood of crack formation. Additionally, properly supporting and fixturing parts during the weld and cool-down phase helps limit movement and distortion, further reducing stress concentrations and improving weld integrity.

ISSUE #4: OVERHEATING

Overheating during laser welding occurs when too much energy is delivered to the weld zone or when thermal management is insufficient. This can lead to several issues, especially in medical devices where components are particularly small, sensitive, and tightly packed. Overheating may cause burn marks or discoloration and create heat-affected zones that alter material properties resulting in dimensional instability or warping. In more severe cases, it can damage nearby plastics, adhesives, or coatings—compromising the overall integrity of the assembly.

To prevent overheating, manufacturers have a couple of options: use heat sinks to draw excess thermal energy away from the weld site and protect surrounding areas, or adjust laser weld parameters.

Integrating heat sinks into the tooling helps pull energy away from the part, keeping overall temperatures lower—a particularly important safeguard for heat-sensitive components. In addition to thermal management through tooling, overheating can also be mitigated by controlling the laser input. This may involve lowering the energy delivered over time by reducing the repetition rate or average power. For CW lasers, increasing the beam travel speed provides another way to reduce energy deposition.



Overheating

Prevent Overheating

Pulse shaping techniques—such as incorporating upslope and downslope profiles—help manage how energy is introduced and withdrawn, reducing thermal shock. Finally, adjusting the laser's focus by fine-tuning the beam's spot size and position ensures that heat is distributed more evenly, allowing for precise control of weld depth and minimizing unintended thermal effects.

CONCLUSION

Laser welding offers unmatched precision and cleanliness in medical device assembly, but only when process variables are well understood and controlled. By proactively addressing common issues such as gaps and selecting the right process parameters to avoid porosity, cracking, and overheating, manufacturers can improve weld quality, reduce scrap, and meet stringent industry standards.

Consistent results start with a validated process, robust monitoring, and the right equipment. With the proper tools and expertise, laser welding can deliver the performance that modern medical devices demand.

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