Spot and seam welding applications using Nd:YAG lasers

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Abstract

With precise energy control and application flexibility pulsed Nd:YAG lasers offer a unique non-contact welding source. The flashlamp pumped (FP) Nd:YAG laser distinguishes itself from other laser sources by providing unrivalled spot welding performance and low heat input seam welding by using peak power not average power to create the weld. In addition with the convenience of fiber delivery and multiple outputs the laser source offers easy and flexible system integration.

The benefits and characteristics of the laser are discussed, with examples of the spot welding and seam welding capabilities, specifically covering the welding of Al-Si alloys, titanium medical implantable devices, precision spot welding in photonic components and battery tabs.

Introduction

The flashlamp pumped (FP) Nd:YAG laser has been utilized for laser welding in the industrial marketplace for over 20 years. Reliability, weld performance, ease of implementation and flexibility of this unique welding source have underpinned the lasers successful implementation across a wide range of manufacturing environments ranging from medical, automotive, aerospace and photonics.

In terms of a general welding source the laser offers a number of unique characteristics over conventional processes such as arc, resistance and plasma sources; a non-contact process, minimal heat input, high flexibility and precise energy control over the heat source, high aspect ratio welds and ease of automation and integration. The flashlamp pumped Nd:YAG laser sets itself apart from other lasers with incredible spot welding performance, from fine spot to penetration applications, and low heat input seam welding. The beam is delivered to the welding area using a flexible fiber optic cable, usually around five (5) meters long. The use of a flexible fiber optic cable greatly facilitates the integration of the laser into turnkey laser welding systems, factory automation equipment and robots.

Flashlamp Pumped Nd:YAG laser welders

The robustness and reliability of the FP Nd:YAG welders comes from the simple laser design, with a solid crystal laser medium, well established power supply technology, and the use of fiber optic beam delivery.

There is a fundamental difference between the welding characteristics of the FP Nd:YAG laser and continuous wave (CW) or q-switched laser sources. The FP Nd:YAG lasers use high peak power millisecond pulses to create welds, with seam welds created by the overlapping pulses. The continuous wave (CW) lasers deliver constant / average power during a seam weld, or can be gated on and off to deliver a marginally higher peak power for spot welds. Q-switched lasers deliver very high peak power nanosecond pulses that have very low energy and so are only suitable for welding foils and very thin materials.

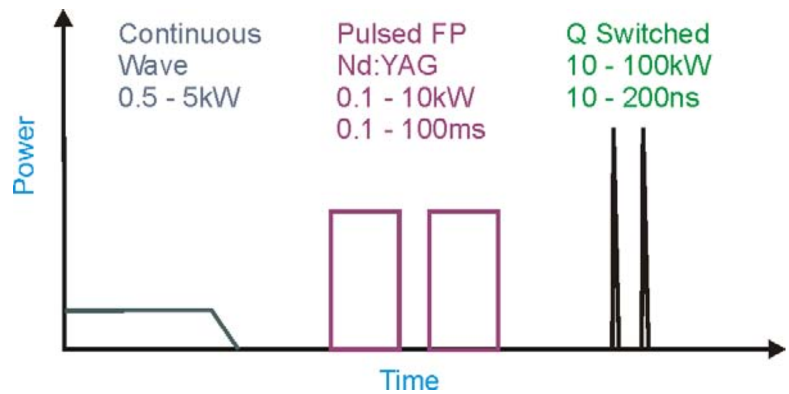
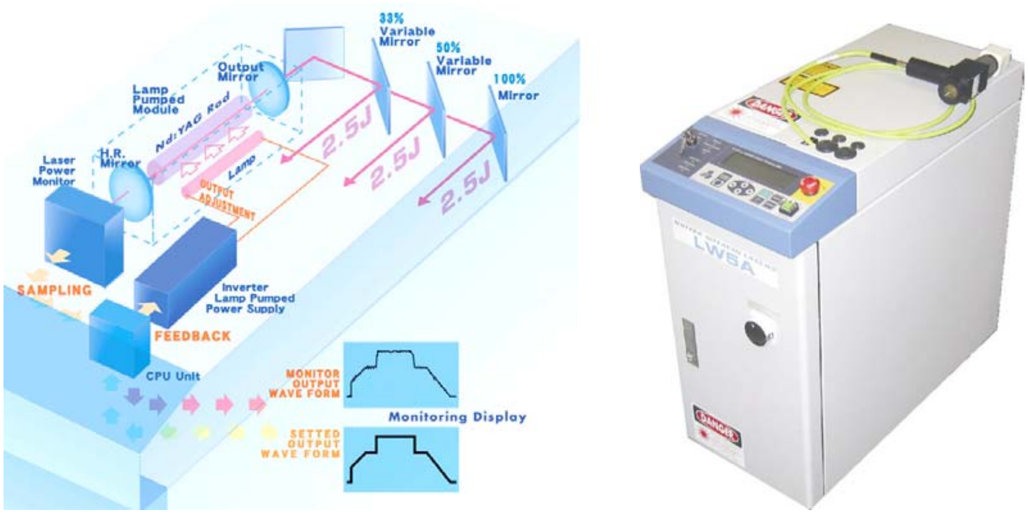


Figure 1 Schematic representation of the output characteristics of various welding laser sources, with peak power and pulse durations ranges where relevant. The FP Nd:YAG laser combines high peak power with sufficiently long pulse widths for usable energy for exceptional spot welding and low heat input seam welding.

The welding performance of the FP Nd:YAG laser in comparison with the CW and Q-switched lasers offers the ability to produce very deep narrow spot welds and low heat input seam welds. As shown in figure 1, the peak power and pulse duration of the FP Nd:YAGs output combines the best of both worlds – high peak power for penetration and a long enough pulse duration for sufficient welding energy. The delivery of the weld energy in a short time period optimizes weld performance by minimizing heat loss through conduction, and the use of high peak powers allows deep penetration welds by relatively small / low average power lasers. For example a 5W average power FP Nd:YAG laser can produce around 2.5kW of peak power that can penetrate 0.03” thick steel. The equivalent CW laser would be significantly more expensive, much larger with higher operating costs.

The generation of the high peak power short duration pulses is through Yttrium Aluminum Garnet (YAG) crystal rod that has been doped with neodymium (Nd), and is optically pumped by flashlamps. The laser cavity is directly mounted to a solid base, is fully sealed and therefore requires almost zero maintenance. The only laser consumable is the flashlamps that typically require replacement after tens of millions of shots.



(a) (b)

Figure 2 (a) Layout of a pulsed Nd:YAG welding laser showing the resonator and optical beam delivery components. Note the real time power feedback and the capability of energy or time sharing. (b) 5W laser unit showing fiber optic and focus head, the unit contains laser cavity, heat exchanger and power supply.

More recent enhancements of the laser include real time power monitoring, pulse shaping, power ramping for seam welding run-out, and increased beam quality or brightness. These are briefly outlined -

Real Time Power Feedback

Each pulse is monitored at a sample rate of 20 kHz to ensure the demanded pulse is reliably produced each time, even from start up. Using pulse width modulation of the power supply and optical feedback, the pulse is monitored and modified in real time to follow the demanded pulse parameters. This ensures excellent pulse to pulse stability and automatically delivers the same pre-set weld over the full life of the flash lamp.

Power Ramping

When completing a seam the weld runs back over the starting point, in some instances causing cracking or porosity. The power ramping feature eliminates these weld defects by incrementally reducing the laser power such that the weld termination is gradual. Power ramping can also be used at the start of the weld to gradually initiate welding. This feature also provides a more cosmetically appealing weld.

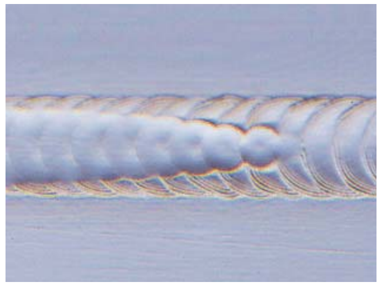


Figure 3 Fadeout capability on seam welds, to prevent last pulse cracking and ensure completion of smooth seam.

Pulse Shaping

In most welding cases a square wave welding pulse is used. However, there are a few applications where the use of pulse shaping can enhance welding usually by alleviating a weld defect. There are numerous pulse shapes, with most lasers offering around 20 points that can be programmed, however, two basic pulse shapes are most commonly used. The first is for overcoming highly reflective material such as copper and aluminum, and the other is to minimize the thermal cycling experienced by the part during welding for materials susceptible to cracking.

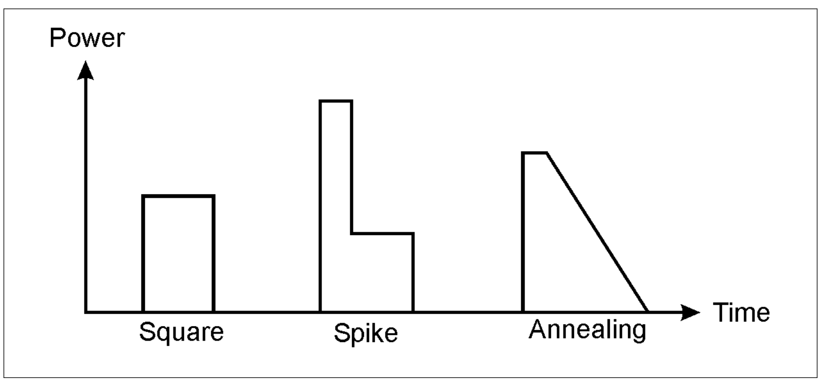


Figure 4 The majority of welding application use a square wave pulse. The two common pulse shapes are the “spike” used for highly reflective material, and the “annealing” that alleviates cracking.

Time Share

The Time Share feature permits one laser to be configured to deliver two or more welds to separate work pieces or separate workstations “sequentially ”. Therefore, one laser can support multiple workstations using different weld schedules at each workstation, which greatly reduces laser costs.

Energy Share
The Energy Share feature permits one laser to be configured to deliver two or more welds to the work piece "simultaneously", thus greatly increasing the number of welds per laser pulse. This can also prevent the requirement of motion that would be required to create multiple welds with a single beam system. Each of the beam "branches" can be properly balanced such that each weld nugget is identical in shape, area and depth.

Welding Applications

The spot and seam welding applications highlighted in figures 5 and 6 indicate the versatility of the laser; with examples of welding hair thick medical guide wires to penetration welds in copper to seam welding aluminum. The flexibility of the power supply, beam delivery and focus optics of the FLP Nd:YAG laser are well suited to provide the required weld width and penetration for each welding process The different power ranges of laser models are complemented by large matrix of delivery fibers and focus heads to provide the optimal focus spot size, and subsequent weld width and penetration for the process.

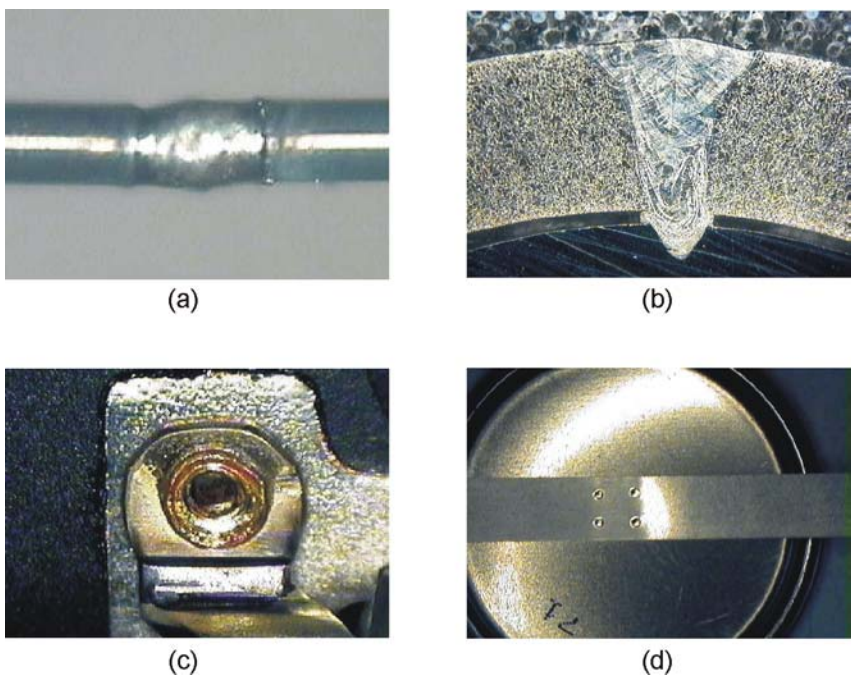


Figure 5 Examples of spot welds (a) Butt weld 0.004" diameter nitinol guide wires (b) Cross section of a lap weld through 0.03" thick steel into nickel (c) Lap weld through 0.02" thick copper for welding of relays (d) Welding battery contact

The seam welds examples in Figure 6 are all applications where weld heat input is critical. The smaller sized kovar packages as well as custom sealing path are problematic for resistance seam sealers in terms of overheating the part or creating the custom seam. The thin walled aluminum battery cases are geared towards FP Nd:YAG laser by material absorptivity and precise control of weld nugget dimensions. The airbag detonator is a classic example where the welding procedure must not overheat the volatile explosive material contained with in. Typically, an FP Nd:YAG laser has less than 50% the heat input of a continuous welding laser source. The final example of disc drive manufacture requires a strict out of plane alignment requirement that requires systematic tacking and welding.

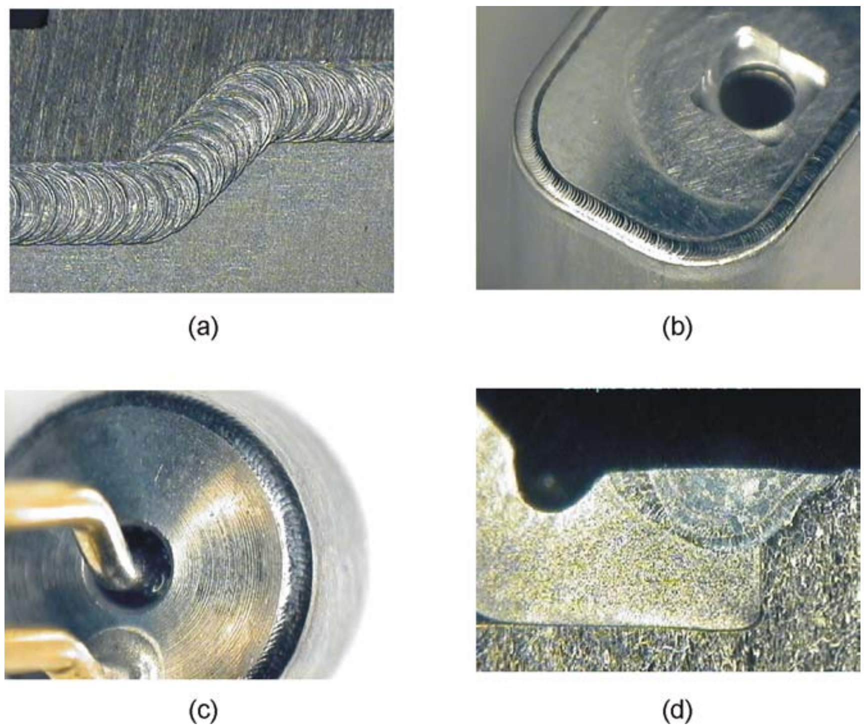


Figure 6 Example of seam welds (a) Kovar lid seam seal (b) Aluminum battery case (c) Stainless steel air bag detonator. (d) Cross section of a disc drive weld

A number of further examples are described in detail -

Welding Al-Si Controlled expansion alloys

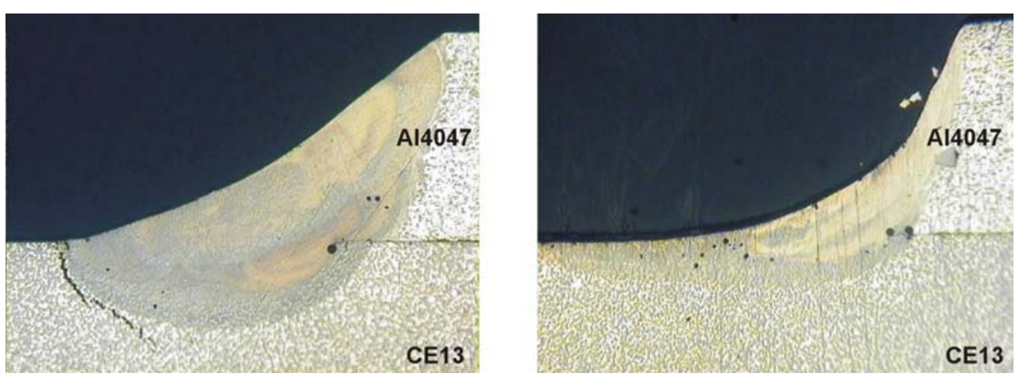
Aluminum Silicon alloys are lightweight, high thermal conductivity alloys that have different ratios of constituents tailored to specific expansion coefficients. The range of alloys and common usage are shown in Table 1. The advantage these alloys over kovar and CuW are reduced weight, increased thermal performance, tailored CTE, high stiffness and ease of manufacture

Composition	CTE 20 –500 C (ppm)	Applications
70Si-30Al	7	RF & microwave packages, Electro-Optical housing, power device base plates.
60Si-40Al	9	
50Si-50Al	11	General electronic packaging, heating blocks in die bonders, components for inertial systems.
40Si-60Al	13	
27Si-73Al	17	

Table 1 Composition and applications for the range of Al-Si alloys.

In constructing a housing or package the body containing the components must be hermetically sealed under vacuum to ensure component operational reliability and longevity. The lid of the package is aluminum, typically 4047. The welding of this lid to the body is problematic due to the mismatch of CTE's of the Al-Si alloy and the aluminum lid, and the weakness of the alloy under the tension forces induced through weld solidification.

In order to successfully weld the alloys beyond a silicon content of 27%, the heat input must be minimized and carefully controlled. The pulsed Nd:YAG laser provides the welding solution by using pulse shaping; Figure 7a indicates the cracking that occurs in the base Al-Si adjacent to the fusion zone under the action of the solidification forces when using a regular weld schedule.



(a) **(b)**

Figure 7 Cross sections of seam welds in CE13, an Osprey metals Al-Si grade with 40% silicon. (a) Welded with square pulse 3.5ms duration, 3.5kW peak power with an average power of 240W and (b) Welded with an annealing pulse shape to eliminate cracking with an average power of 70W.

Figure 7b shows a crack free weld - although the heat input has been minimized as evident by the reduced fusion volume, this in itself did not prevent cracking. A high peak power annealing pulse shape was used to produce reliable crack free welds and increase the process window. The annealed pulse used 7.5kW peak power to create the weld, and then a 1.5kW peak power tail to anneal the weld. The ability to create the fillet weld between the 0.02" thick aluminum lid and the base alloy using only 70W average power is simply not possible using another laser source.

Welding Titanium Medical Implantable Devices

These devices include pacemakers, as well as various other types used to control various activities with in the body and brain. The electronics are housed in thin walled titanium clamshell cases that require a high quality hermetic seal. The weld must seal the package while not overheating the electronics inside or distorting the 300 micron thick cases. This type of welding application is well suited to the pulsed Nd:YAG laser, where heat input control and weld quality are key. The laser is also compatible with the need to weld titanium in a highly inert welding atmosphere that is carried out with in a sealed glove box.

A feature of the pulsed laser when welding two or three dimension seams is that the frequency of the laser pulsing can be directly linked to the welding speed. Therefore, when transitioning from faster straight lines to slower corners and bends the decrease in welding speed can be synchronized to a reduction in laser pulsing frequency.

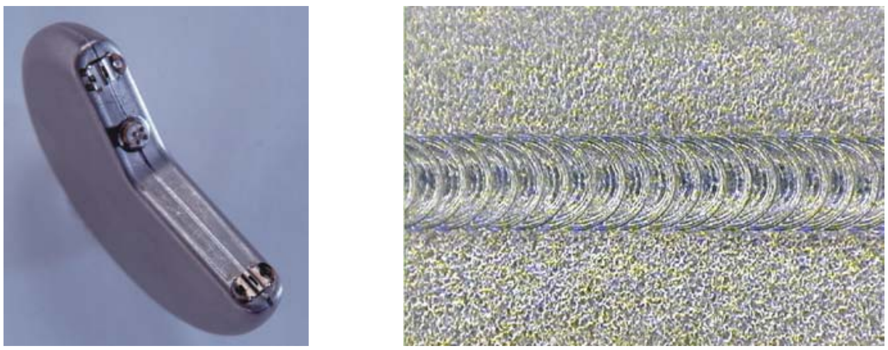
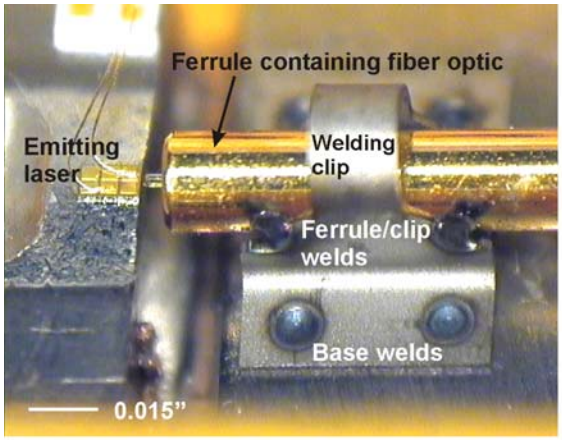


Figure 8 Welded titanium implantable device and magnified image of the weld seam.

Precision Spot Welding in Photonic Components

The manufacture of photonic devices requires alignment and fixing of components that transmit communications signal by light through fiber optic cables. The core diameter of these fibers is nominally 9 microns, and any misalignment creates significant signal loss. Typically the alignment tolerance when fixing the fiber optic to an active transmitting laser is sub micron. The joining method preferred by the industry is spot welding using FP Nd:YAG lasers.   Figure 9 shows such a welded assembly.



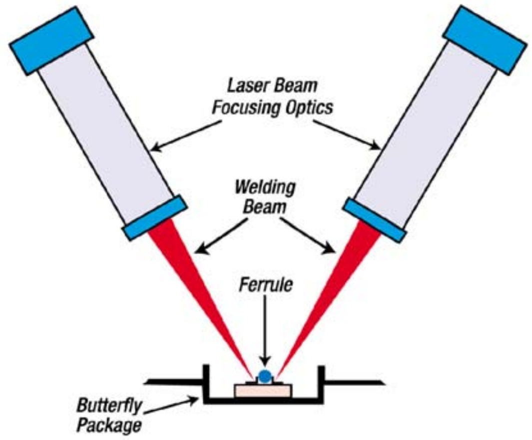


Figure 9 A welded sub-assembly, with the kovar welding clip fixed to a base and the gold coated kovar ferrule joined to the welding clip. Welds are placed either side of the welding clip to balance weld shrinkage and minimize loss of alignment.

The un-welded assembly containing the ferrule that houses the fiber is optically aligned to the emitting laser. Once aligned the laser spot welds the 0.008” thick welding clip to a base and then the 0.04” diameter gold coated kovar ferrule to the welding clip. This latter weld is the where the most optical misalignment occurs. This weld geometry is a fillet weld with a nominal weld gap between the round ferrule and the square weld clip shoulder of 20 microns. By optimizing weld spot size and weld schedule, as well as welding simultaneously on each side of the clip with energy balanced weld heads the misalignment due to weld shrinkage can be controlled to under 5 microns.

This assembly known as a butterfly style package, and is one of the many photonics devices that use laser welding, other include transmitters and receivers, and passive devices.

Battery Tab welding

The key concern when welding a battery tab to the case is that the weld nugget must not penetrate through the battery casing. This creates loss of power and reduces the lifetime of the battery. The battery tab is nickel and around 0.003” thick, and the case is stainless steel, and is nominally around 0.005” thick. Therefore weld penetration must be controlled to ± 0.0015”. This can be further complicated when the welding surface of the battery case is not smooth.

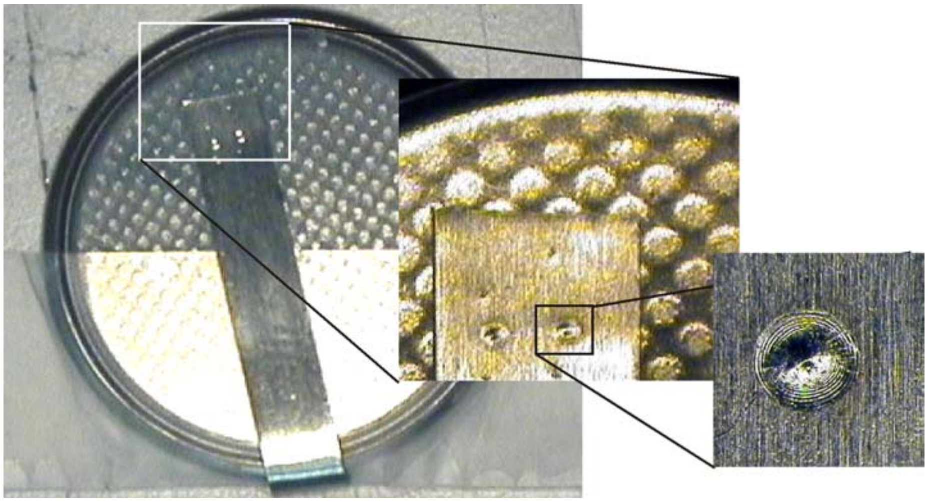


Figure 10 Progressively magnified images of the nickel battery tab weld to the stainless steel casing.

To achieve the precise weld penetration the spot is made using a low peak power pulse such that welding is conduction mode. This low energy density welding provides excellent penetration control something that is not as easily managed using the high penetration mode of keyhole welding.

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