AMADA WELD TECH

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Subject: Challenging micro weld applications – solutions and parameter development for pulsed Nd:YAG lasers

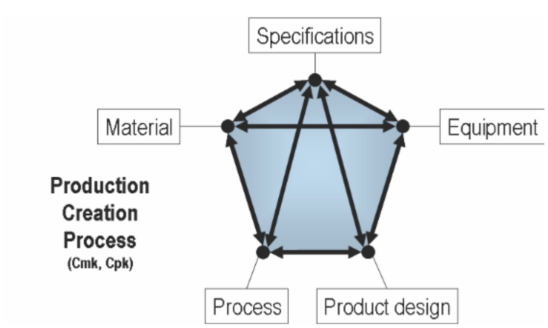
Introduction

Laser welding applications are getting increasingly complicated. The drive towards smaller and cheaper products often results in the need to make high quality laser welds using less than suitable materials. Especially the automotive sector comes to mind where difficult to weld materials such as Copper and Brass are often employed.

Successful welding of these components requires the development of a weld schedule with a reasonable process window. The use of pulsed Nd:YAG laser with support for pulse shaping can help to significantly increase the process window.

Pulse shaping, which is the "art and science" of finding the optimum amplitude versus time curve for the laser pulse provides a number of exciting possibilities. It can help in increasing the weld penetration depth while maintaining a small pulse energy, which is often needed in the seam welding of heat sensitive parts. It also can provide for part conditioning prior to welding and post conditioning to reduce the cooling rate of the weld to reduce weld defects such as cracks, inclusions and weld porosity.

Key to success for development of a robust laser welding manufacturing process is when during the design phase of a product the laser welding process considerations are taken in account and designed into the product. Normally a product is developed based on the functional parameters of this product. Fields of expertise to be taken in account during the development of a new application are; laser weld process, product design, material properties and manufacturing equipment.



This article discusses the approach of development of pulsed Nd:YAG laser parameters for challenging micro weld applications. The goal of a laser application development to find out the best technical execution of the manufacturing process.

One speaks of micro welding when the material thickness is no more then 0.5mm for flat products and the diameter is less then 1mm for round shaped products.

Effect of laser welding parameters

During the development of a laser welding process many considerations with respect to the application, such as:

- Final assembly accuracy, which means no distortion caused by the welding process.
- Corrosion effects of the laser weld.
- Metallurgical microstructure in the melt zone, which means no cracks, no voids or brittle phases.

Optimization of the process parameters is essential to meet the specifications of the application. The laser welding process has many parameters; most common parameters are described in table 1.

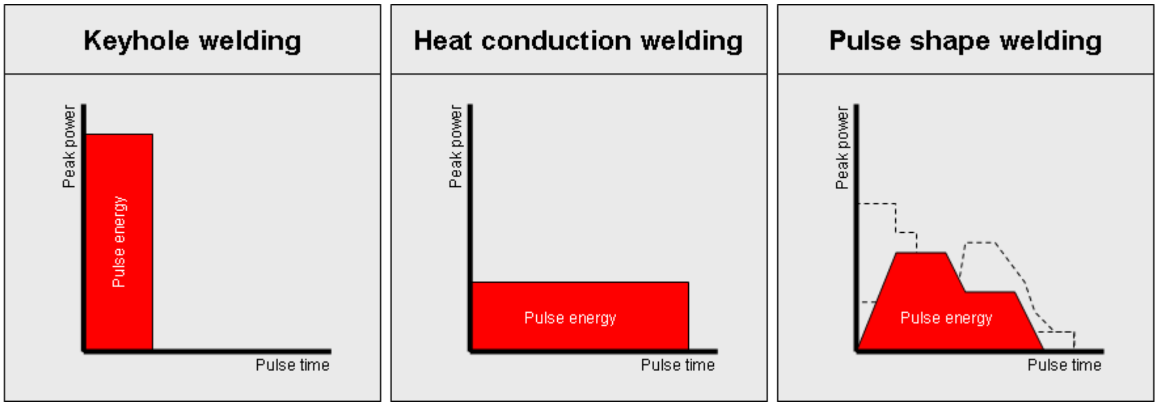
Table 1: Overview of most common laser weld parameters

Parameter	Effect	Comment
Pulse time [ms]	Melt volume	A combination of these parameters results in amount of evaporated metal and therefore the amount of contamination on the work piece or equipment
Pulse peak power [W]	Weld penetration depth	
Pulse energy [J]	Melt volume	
Pulse frequency [Hz]	Spot overlap	Hermetic seam welding
Spot size [um]		~ 1 to 2x material thickness
Spot energy distribution	Penetration depth	
Number of spots	Weld strength	
Sequential/Simultaneous	Distortion	Final assembly accuracy

Goal of the parameter development for micro welding is to find out the best technical execution of the welding process. Technical execution of such a process consists of material selection, laser weld geometry product design and tooling design. Statistical robustness of the process needs to be proven and a selection of laser source suitable for mass production.

A key to success for development of a robust manufacturing process is good teamwork between product developers, equipment constructors and laser weld process experts.

Laser weld power versus pulse time
3 main groups of laser welding can be determined, most common used are keyhole welding and heat conduction welding. Laser welding using a shaped pulse is used in approximately 20% of the laser welding applications.



Keyhole welding
Parameters settings for keyhole welding are typically a high peak power at a short pulse time (<5ms), or in other words welding with high power density. For keyhole welding the depth of the weld is more than the width of the weld. This high power density opens the melt resulting in a deep penetration of the weld. A keyhole welding process is selected when:

- The application demands a deep penetration combined with little heat affected zone.
- A high reflective material with high thermal conduction needs to be welded, such as copper and aluminum.
- A bad fit between components needs to be bridged. Using keyhole welding about 50% of the material thickness can be bridged as a gap.

The down side of keyhole welding is that this weld parameter leads to more contamination of the parts, equipment and optics. Due to high power density the surface of the melt is overheated and evaporated. The metal vapor deposits near the weld position.

Heat conduction welding
Heat conduction welding has typically a low peak power and a long pulse time (>15ms). The energy required to generate a melt volume is put into the material by heat conduction, not like keyhole welding where the melt is opened. The penetration depth is rather shallow, the penetration depth is less then the width of the weld. A heat conduction weld is selected when:

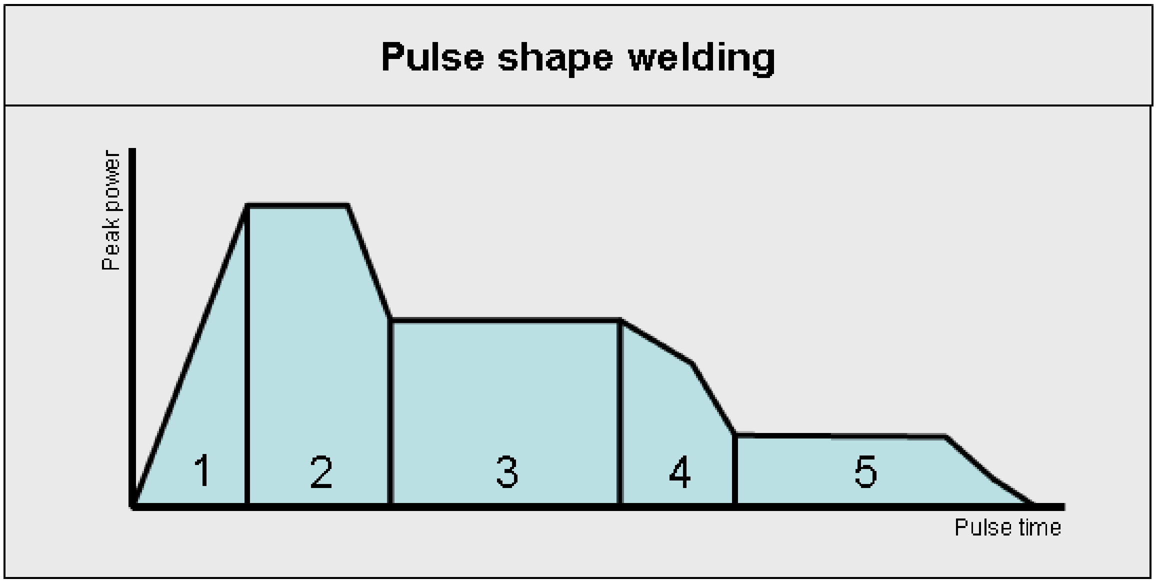
- Clean laser welding is essential.
- A tube needs to be sealed and high melt volumes needs to be made.

The down side of heat conduction welding is that no gaps can be bridged by this welding process.

Pulse shaping
A laser pulse is considered shaped when the power is varied during the pulse time. Pulse shaping gives very much freedom in programming and makes it therefore challenging to

develop the best pulse shape. However pulse shaping enables welding of material combinations and product designs that are not possible by using keyhole welding and heat conduction welding. Developing a pulse shape enables optimized penetration depth of the weld without causing high contamination or splashes. It even enables welding of challenging material combinations. In other words using pulse shaping combines the best of Keyhole welding and Heat conduction welding.

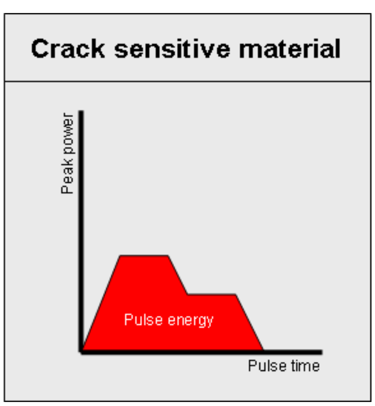
For a laser pulse shape 5 phases of the weld process can be determined.



1) Initiation of the melt in material A (laser light absorption)
2) Start of the melt growth of material A
3) Initiation and start of weld between material A and B
4) Stabilizing of the weld between material A and B
5) Controlled cooling down of the weld.

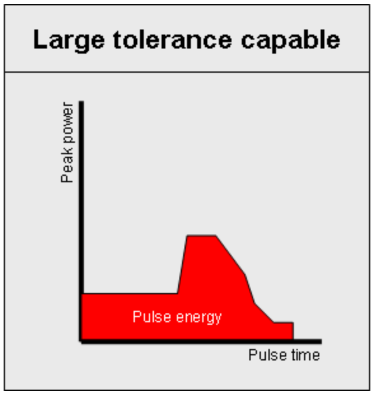
Development of the pulse shape depends strongly on what needs to be achieved by the laser weld, this can be a material type or combination which requires a controlled cooling down of the weld or a product tolerance that causes a gap between components that needs to be bridged or a material that has a temperature dependant laser light absorption.

Typical pulse shapes

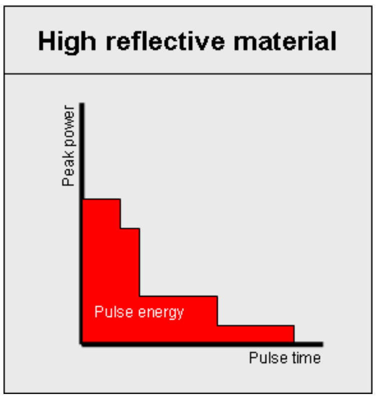


A typical pulse shape for crack sensitive materials has an upslope at the beginning of the pulse to prevent thermo shock and a down slope at the end of the pulse to have a controlled cooling down period.

Stainless steel materials with high C content are cracks sensitive from the material point of view itself and material combinations can lead to brittle structures, by controlling the cooling down phase the thermal shrinkage stresses are reduced.



Normally laser welding requires high accuracy of the components, a good thermal contact between the parts is essential. The smaller the components get the more difficult it is to achieve such high component accuracies. By using a pulse shape it is possible to bridge gaps between components of 100% of their material thickness. The pulse shape has typically a low peak power for about 15ms to melt material A. When a full melt is generated the peak power is increased suddenly to push the melt volume to material B. When material A has contacted material B the laser power is reduced gradually to stable the melt and to cool down.

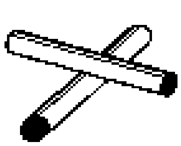


For high reflective materials it is difficult to put the energy in the material as most of the energy is reflected by the material. In order to get energy in the material so it melts requires a high peak power. For most high reflective materials the absorption rate depends on the material temperature. In other words when the material is molten the absorption rate increases rapidly. When the laser pulse is made at a steady peak power the weld will overheat and splash out. Therefore pulse shaping is essential to reduce the peak power rapidly once a melt is made. The power is reduced and the melt grows under low peak power and long pulse time.

Weld geometries

One of the key criteria for laser welding is the design of the components. Especially availability of material is essential for proper laser welding. Normally no extra material is added to the weld. Other aspect for laser welding is good thermal contact between the parts. As the most of the energy is distributed to the upper material the lower material is only heated up by thermal conduction. So to be able to heat up the lower part a good thermal contact is essential.

Pictures below show some typical laser configurations: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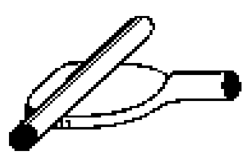
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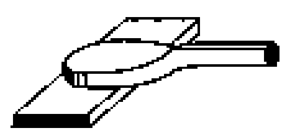

vlakkontakt

Point contact: Has a poor thermal contact and is therefore not recommended for laser welding.

Line contact: Has a moderate heat contact and can be applied under special conditions.

Plane contact: Good thermal contact and is mostly preferred for laser welding.

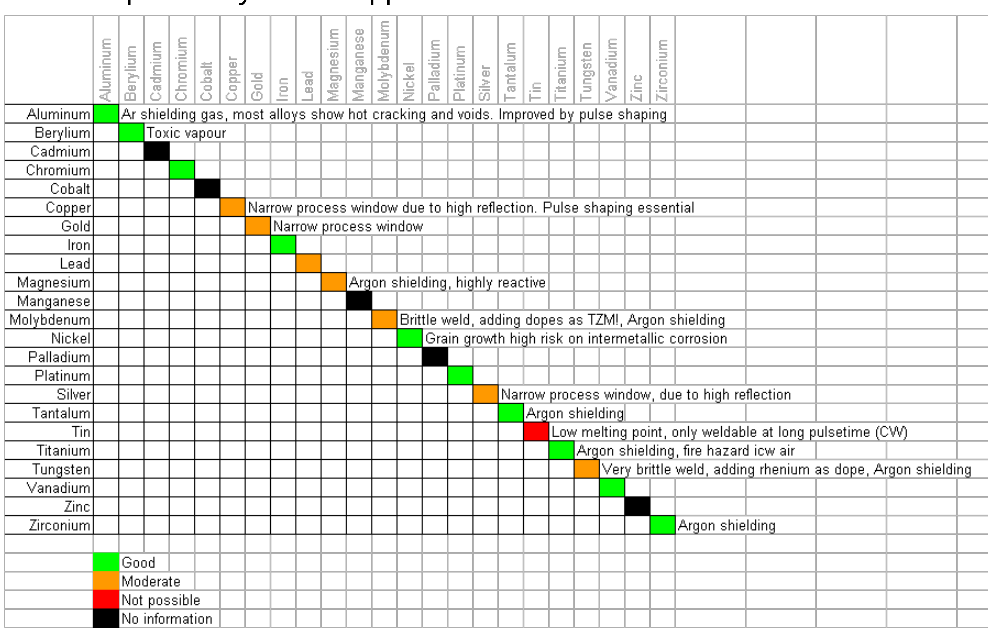
Table 2 describes two most common weld geometries and their most important considerations and boundaries.

Table 2: Penetration welding and overlap fillet welding

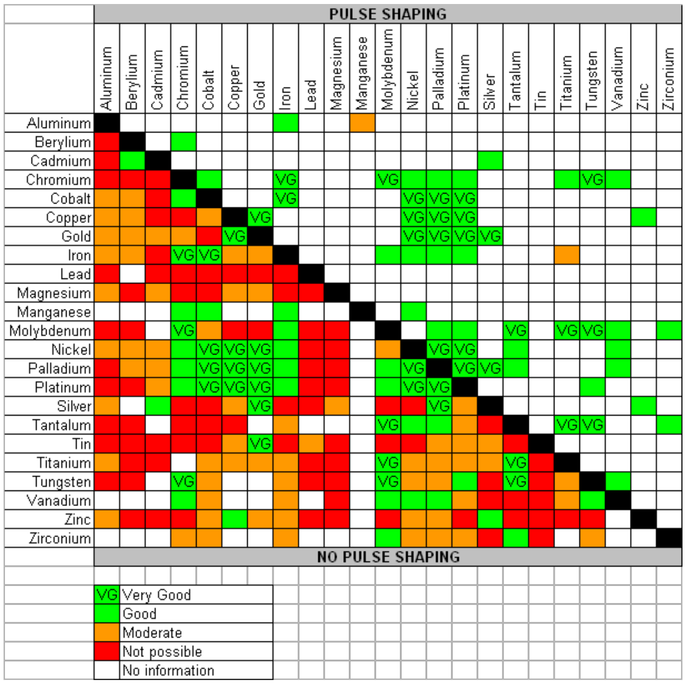
	Penetration weld	Overlap fillet weld
		
Material thickness	0.020 – 0.5mm	0.1 – 0.7mm
Maximum gap	40 – 50% of material thickness	60 – 70% of material thickness
Spot positioning accuracy	Not critical	±0.1mm with respect to material edge
Distortion	< 4um is possible	~ 10um
Visual inspectable	Difficult	Good

Materials for laser welding

Matrix below gives an overview of weld ability for welding similar metals together, it is also indicated when a special type of gas shielding is required. The green marked materials are good to weld, as shown in the matrix some require a pulse shape of gas shielding. The orange marked materials can only be welded under special conditions which have to be studied specifically for the application.



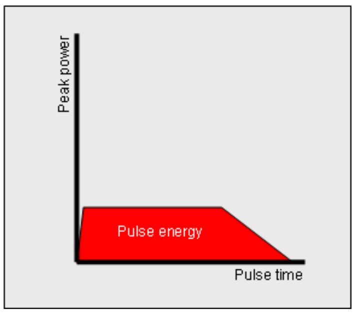
Matrix below gives an overview of the weld ability for dissimilar material combinations and if it is either possible by basic pulse shape welding or a special pulse shape is required.



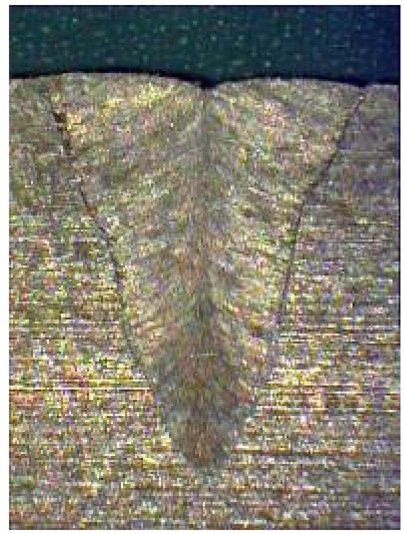
Application test cases

Optimized penetration depth

Seam welding using pulsed Nd:YAG lasers it is quite hard to achieve a high penetration weld without causing splashes or voids in the weld. Demonstrated in picture 1 is a seam weld made in stainless steel, at the lower end of the weld a large void is seen. By optimizing the process by applying a down sloped pulse shape one is able to prevent void formation in the weld. The controlled cooling down prevents gasses to be entrapped in the weld.



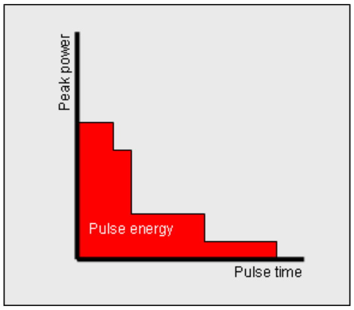
Picture 1: Seam weld, standard keyhole welding

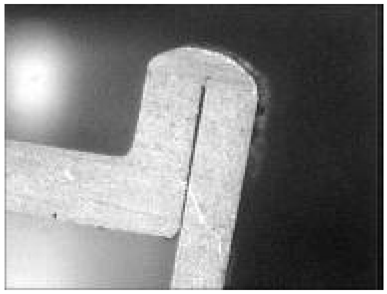


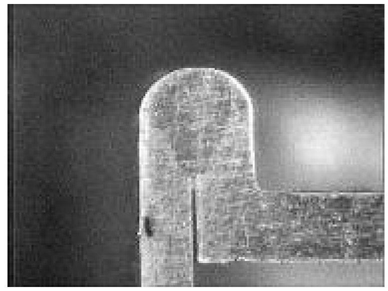
Picture 2: Seam weld, pulse shaping

High reflective materials

Welding of high reflective materials for Nd:YAG laser welding is challenging as most of the energy is reflected by the material. On the one hand the high reflectivity means that high peak power is required to generate a melt in the material; on the other hand the high thermal conduction makes it hard to let the melt grow. Normally one chooses a high peak power to overcome the reflection and a short pulse time to prevent the melt from overheating. This results in shallow penetration depth as is demonstrated in picture 3. By applying a pulse shape the penetration can be increased. First step is to overcome the reflection by high peak power at a very short time, the power is reduced in steps to prevent overheating while growing the melt.





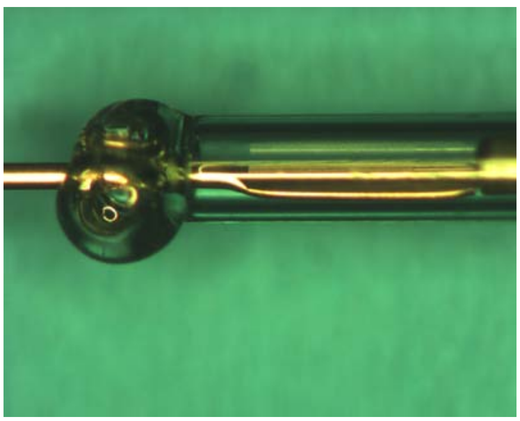


Picture 3: Seam weld in Al, standard keyhole welding

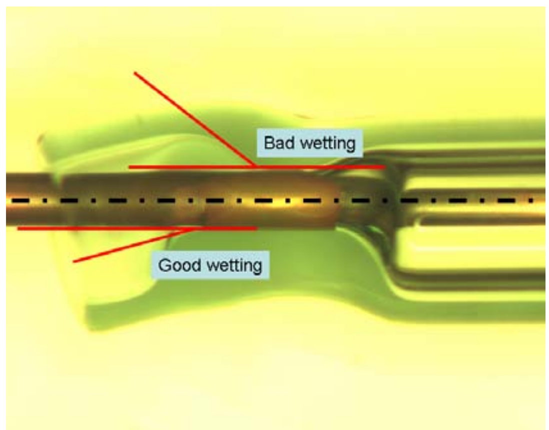
Picture 4: Seam weld in Al, pulse shaping

Glass to metal joint

This application describes sealing of a glass to metal feed-through in a high vacuum environment using a pulsed Nd:YAG laser. The sealing process is a balance between sufficient energy to create sufficient melt volume to seal the tube without overheating a section of the melt. Overheating a section of the melt in a low pressure environment results in cooking of the glass and large bubbles are generated, as is shown in picture 5



Picture 5: Overheated glass



Picture 6: Good wetting vs bad wetting

Good wetting of the molten glass to the feed-through wire is essential for a vacuum tight seal. Wetting behaviour depends on the temperature of the melt and the temperature of the wire. A sample is made to show the difference between good wetting and bad wetting, this is demonstrated in picture 6.

To balance the energy input to the glass it is chosen to use galvo mirror scanners to move the laser spot over the sample while increasing the global temperature of the glass tube. When the local temperature (spot position) is too high a bubble is directly initiated in the glass melt. So a balance needs to be found in local energy to prevent bubble formation and global energy to heat up the glass at sufficient temperature to initiate wetting of the glass to the metal pin.

To balance the temperatures the maximum limit of local energy is determined by the bubble formation in the glass (laser process parameters: peak power, pulse time and pulse frequency), global temperature is determined based on leakage tight sealing without bubble formation by optimizing the galvo scan profile as is explained in figure 1.

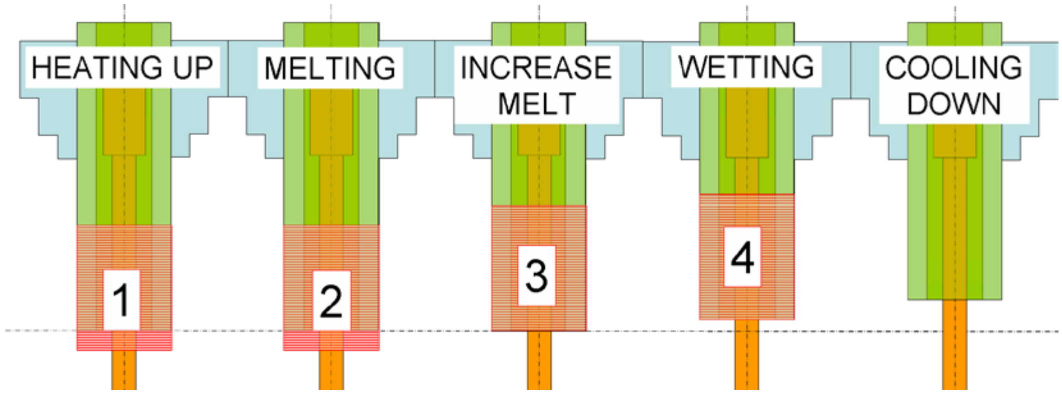


Figure 1:laser seal scan program

The scanner file consists of 4 equal rectangular shapes which run over the glass tube sequentially.

Scan figure 1 is positioned at the end of the glass tube and heats up the glass just below the melting temperature.

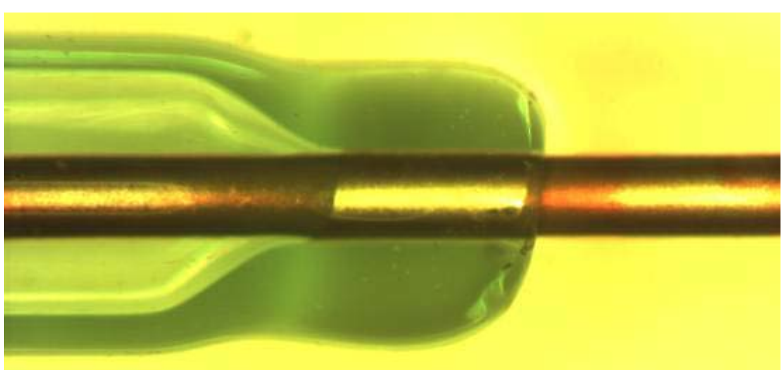
Scan figure 2 is positioned at the same position as figure 1 and melts the end of the glass tube.

Scan figure 3 is shifted upwards to follow the melt path while increasing the melt volume. When the glass tube is molten the melt tends to retract. In this phase the melt touches the wire, but no wetting has taken place during this step.

Scan figure 4 is shifted upwards to follow the melt while increasing the temperature of the glass to initiate wetting between the wire and the molten glass. Experiments have shown that this step is the most critical step in bubble formation, if the temperature is too high, either at the surface of the glass or at the interface between glass and wire bubbles.

The glass tube is cooled down naturally, during this phase the laser is switched of.

Picture 7: Glass seal made with optimized process parameters



Summary
Laser welding applications are getting increasingly complicated. The drive towards smaller and cheaper products often results in the need to make high quality laser welds using less than suitable materials. Especially the automotive sector comes to mind where difficult to weld materials such as Copper and Brass are often employed.

Successful welding of these components requires the development of a weld schedule with a reasonable process window. The use of pulsed Nd:YAG laser with support for pulse shaping can help to significantly increase the process window.

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This article describes typical main features to consider for micro laser welding applications, including some selected true life welding applications as an example.

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