Melexis

INSPIRED ENGINEERING

APPLICATION NOTE

Guidelines for welding of PCB-less devices (v1.0)

May 2021

Advanced Customer Solutions

Guidelines for welding of PCB-less devices

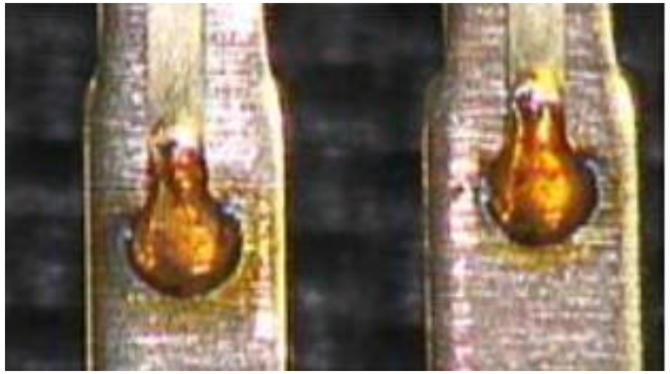
1. Scope

Welding of PCB-less devices

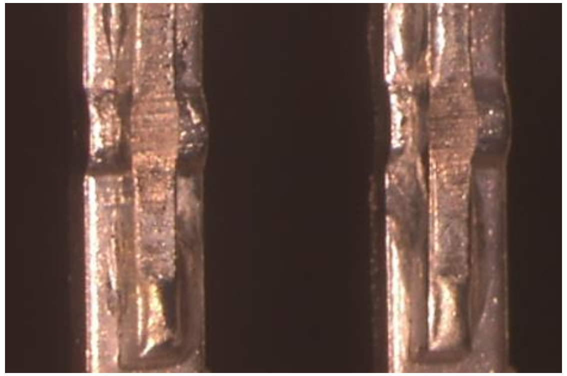
Welding is a process of electrically connecting the core material of IC (Integrated Circuit) leads to the customer housing terminals without an extra connecting alloy (solder). Both Electric Resistance Welding (ERW) and Laser Welding (LW) are possible on PCB-less devices leads.

Usually the housing terminals are of similar metal alloy as the IC leads. Welding to dissimilar metal alloys is also possible (i.e. steel) but requires more attention in parameters settings and control.

The welding joint should be strong enough to survive thermal elongation stress – the value of this stress depends on the construction dimensions and overall length of welded IC and terminal. Maximum stress value is usually by thermomechanical simulation of IC integrated into the module. It should also withstand fatigue stress caused by thermal excursions and vibrations.



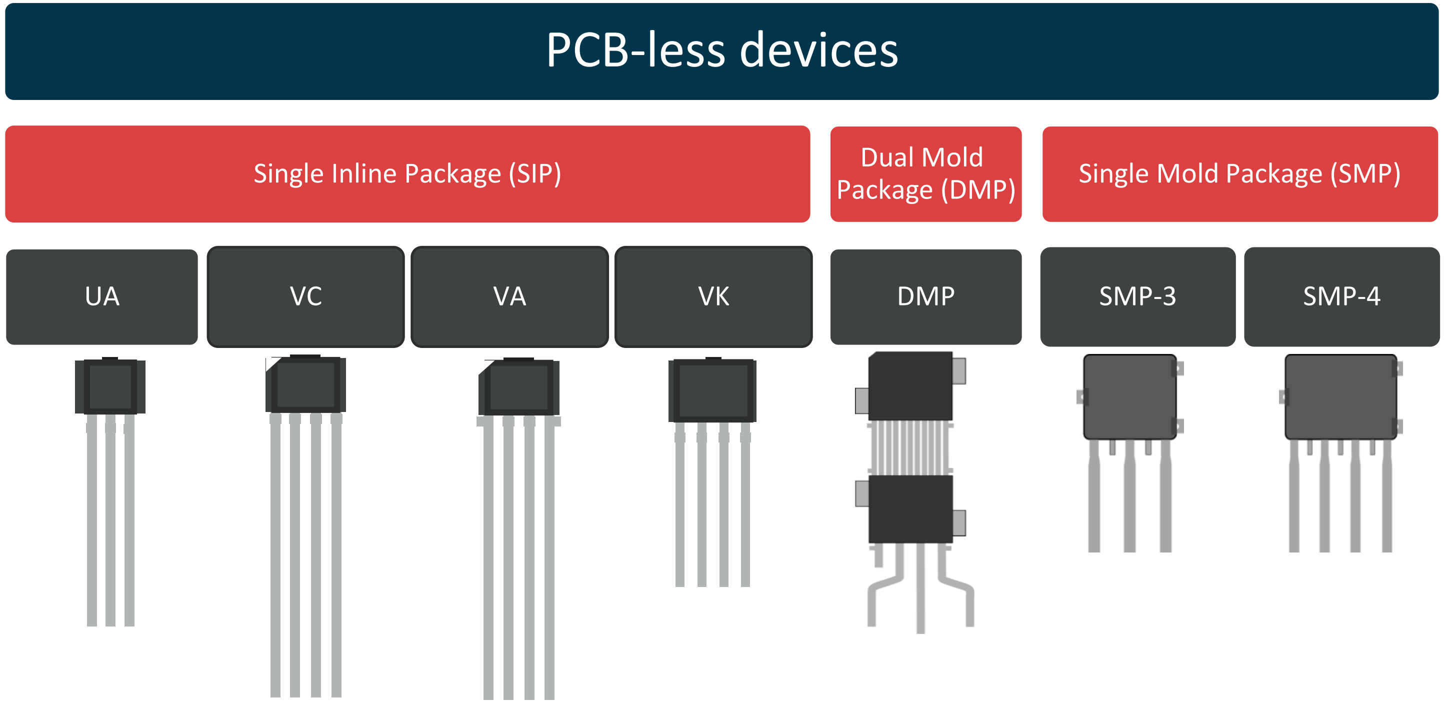
Example of Laser Welding (LW)



Example of Electric Resistance Welding(ERW)

1. Scope

Family of Melexis packages for PCB-less applications

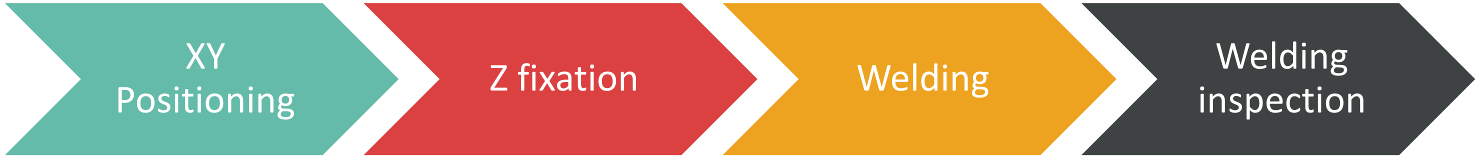


Refer to Annex I for the different abbreviations

The leads of Melexis PCB-less devices are made out of Copper (Cu) with a thickness ranging from 0.2 mm to 0.4 mm, and have a surface finish of tin (Sn) with a thickness of 7.5 up to 15um.

1. Scope

Basic welding flow for PCB-less applications



Welding of an IC to customer housing usually consists on the following steps:

1. **XY positioning:** XY positioning is needed so the center of the IC pin to the terminal welding location
2. **Z fixation**: Permanent Z fixation is always recommended, since the IC can lift even with temporary pusher applied during welding. LW needs a pusher to achieve minimum distance between terminals. ERW does not need a pusher because the electrodes apply pressure during welding.
3. **Welding**: LW heats up the terminals above the melting point by laser energy; ERW softens the metals by reaching a temperature above softening but below the melting point and forging them together under the electrode pressure.
4. **Welding Inspection**: Welding inspection consists of welding joint appearance inspection and sample-based destructive test to measure the pull strength

Storage and handling of Melexis devices at customer side should follow guidelines in J-STD-033 *Handling, Packing, Shipping and Use of Moisture/Reflow Sensitive Surface Mount Devices*. Key parameters are printed on the label attached to the product packing. Refer to *Guidelines for storage and handling of plastic encapsulated ICs* on Melexis website for details.

Guidelines for welding of PCB-less devices

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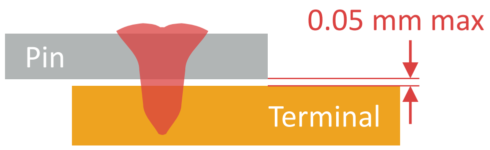
2. Laser welding (LW)

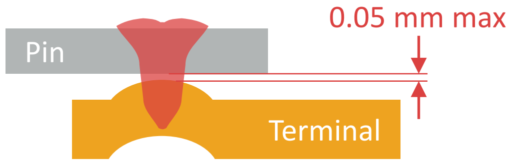
Common configurations for laser welding

The following configurations are valid for spot or seam welding. For successful laser welding, the clearance between pin and terminal has to be as small as possible. Depending on the welding configuration and the laser beam direction, minimum clearance values are shown below. A temporary pusher on IC pin(s) may help to achieve it.

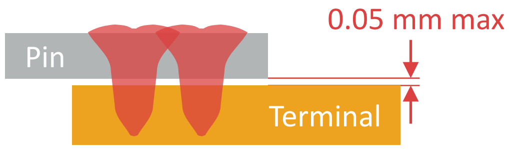
No rework is allowed since it might lead to overheating of the mold body



1 – Single spot stake welding of flat pin/terminal
Standard configuration

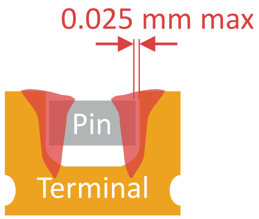


2 – Single spot stake welding of flat pin/terminal with projection
Configuration to secure zero clearance at the welding location



3 – Dual spot stake welding of flat pin/terminal
Preferred to single spot to increase the strength of the joint

4 – Fillet welding
Usually for short leads where there is no space for dual spot



5 – Fork/butt welding
Increased strength of the joint due to the dual side welding, but it is a challenging configuration because of the small clearance needed.

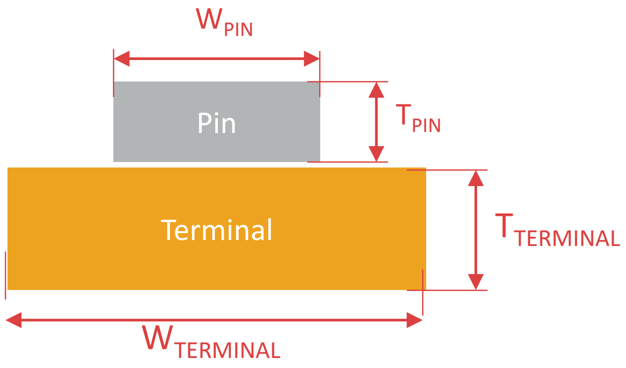
2. Laser welding (LW)

Housing terminal design for LW

Best welding results are achieved when the housing terminal material is copper (Cu) or a copper alloy such as CuSn6 or CuFe2P. Successful welding has been applied to housing terminals thickness from 0.3mm to 0.8mm. To limit the time and transmitted laser energy, the housing terminal should not be much larger than the IC lead. This will also prevent overmelting of the smaller IC lead until the larger housing terminal starts melting. The recommended limits are shown below:

$T_{TERMINAL} \leq 3 \times T_{PIN}$

$W_{TERMINAL} \leq 3 \times W_{PIN}$



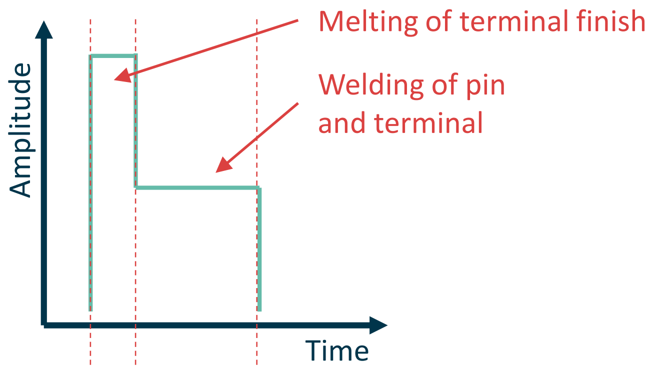
2. Laser welding (LW)

Welding of highly reflective terminal finishes

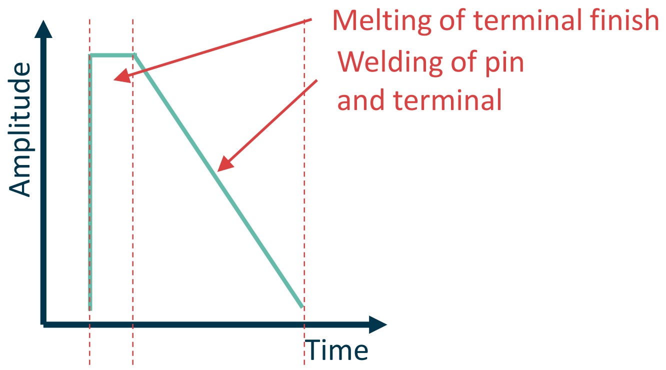
The surface finish of the IC leads and housing terminal plays an important role in laser welding because of the reflectivity of the 1064nm wavelength used by most industrial lasers. There are two solutions to prevent pin degradation due to high reflectivity:

1. To use a laser source with 532 nm wavelength (green) on which gold is reflecting only 50% of laser power
2. To modulate the laser pulse by time and amplitude: after melting the top few microns, the reflectivity drops and the power can be reduced accordingly before the pin sustains any damage

Surface finish	Reflectivity (1064nm)
Gold	90%
Tin	40 – 50%
Bare copper	90%
Nickel	40 - 50%



Step laser pulse modulation

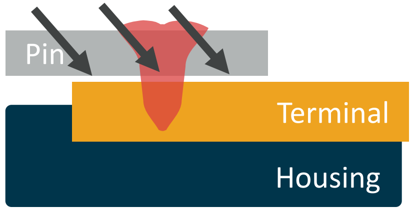


Saw laser pulse modulation

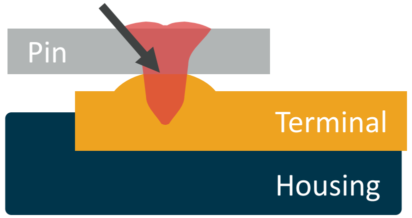
2. Laser welding (LW)

Achieving contact to terminal at the target LW location

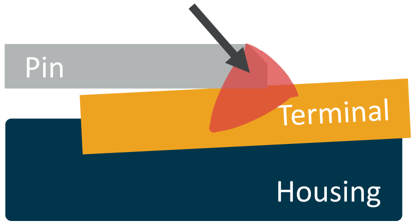
SIDE VIEW



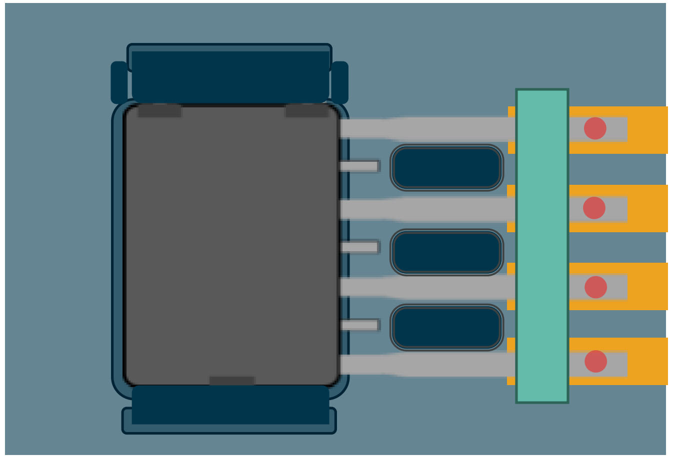
Undefined contact point



Contact point at projection



Contact point at tip



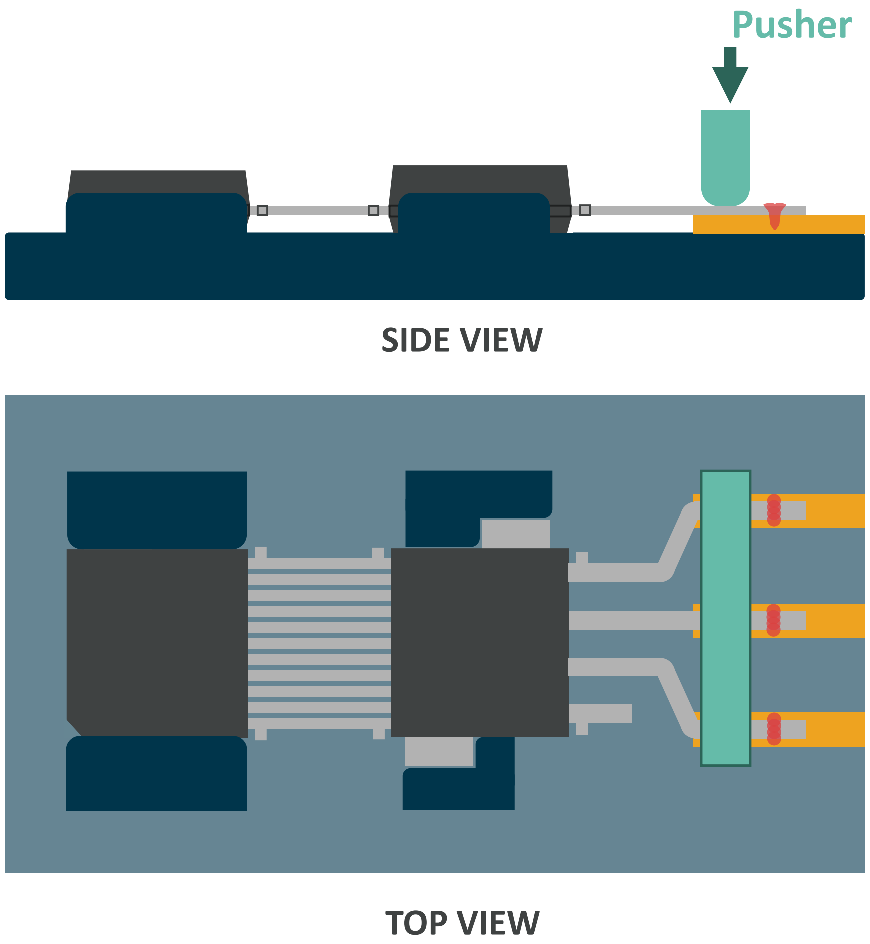
TOP VIEW

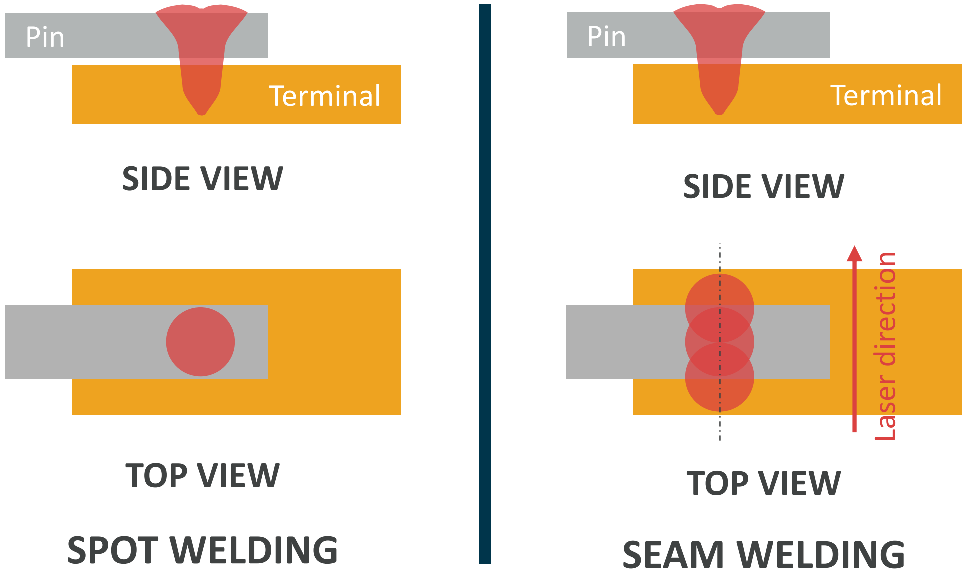
It is recommended the use of a soft pusher (with rounded edges) to secure a minimum clearance between the IC lead and housing terminal at the welding point. This is best achieved with a projection because the point of contact is allocated.

It is also possible secure terminal contact by design through a small spring load on IC pin after Z fixation, either to a projection on terminal or to a tilted housing terminal for laser welding at lead tip (fillet welding).

2. Laser welding (LW)

Seam welding versus spot welding

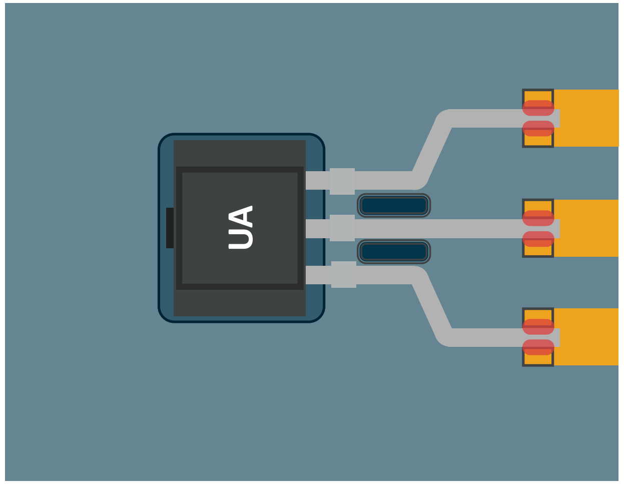




Both spot and seam welding can be used. Seam welding can be achieved by indexing the laser shots with 50% overlapping of the welds. Attention has to be taken to avoid cutting the IC lead by the laser instead of welding both metals together

2. Laser welding (LW)

Welding on fork-shape terminal



TOP VIEW

Welding to a fork terminal requires a minimum side gap between the pin and the terminal to be able to melt and forge both materials in a short time. The terminal height should be kept to a minimum, otherwise a lot of material needs to be melted before reaching the pin. It is advisable to add self-alignment features (chamfers) to the fork to help insert and align the pin to the terminal.

However, fork terminals are better suited for ERW.

Guidelines for welding of PCB-less devices

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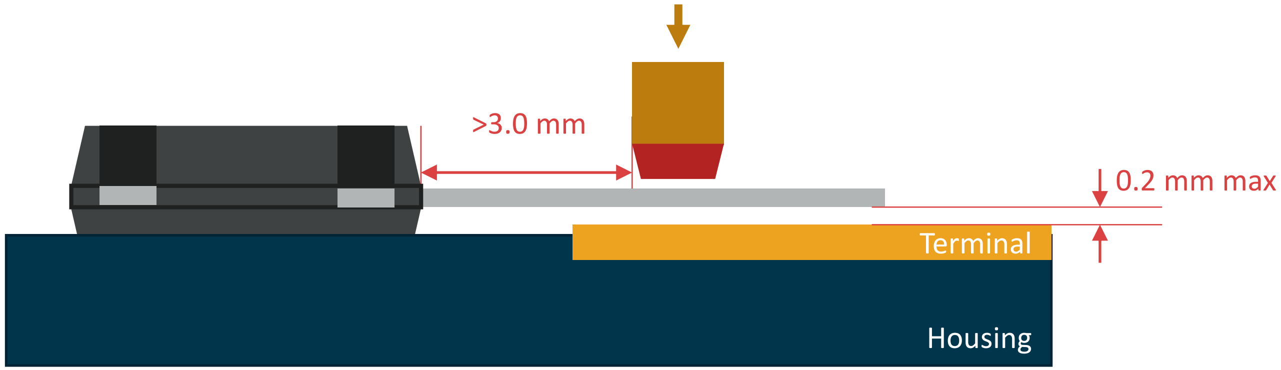
3. Electric Resistance Welding (ERW)

Position of electrode and gap between IC leads and terminal

Before welding, a maximum of 0.2mm gap between IC leads and housing terminals shall be secured. Larger gap may introduce a **permanent spring load** of IC leads versus the mold package due to excessive pressure applied by the electrodes.

The distance of the welding spot to the mold body depends on current, housing terminal mass, electrode dimensions… Melexis experience is that 3 mm from electrode to mold body is usually sufficient to avoid heating the mold body at lead interface over 270 degC. The distance can be less than 3 mm if the condition of <270C at mold-lead interface is met.

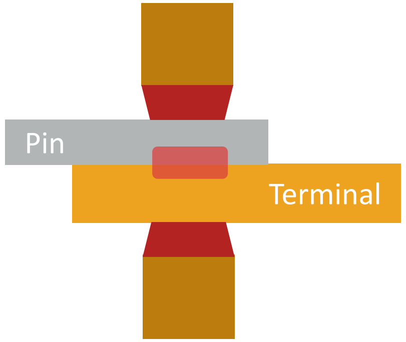
Mold-to-lead interface heating above 270C during the welding process might cause delamination and internal structural damage**.**



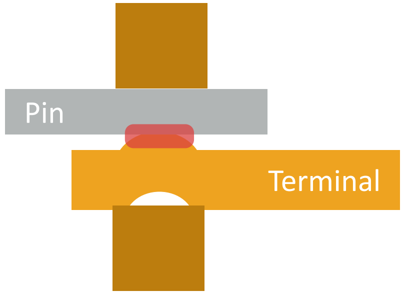
3. Electric Resistance Welding (ERW)

Common **two side** electrodes configurations for ERW

Two side electrodes configurations can be used when there is access for electrodes to the two sides of welding lead/terminal.
No rework is allowed since it might lead to overheating of the mold body



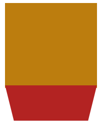
1 – Two side electrodes welding of flat pin/terminal
Standard configuration when the bottom electrode has access to the terminal



2 – Two side electrode welding of flat pin/terminal with projection
The high resistance contact at the bump is a heat dissipation point, allowing the use of low resistance electrodes

3 – Two side electrode welding of pin in fork terminal
Requires more complex terminal shape

4 – Two side electrode welding of 90 deg bent pin and terminal
Requires 90deg pre-bending of IC pins

 **High resistance electrode**

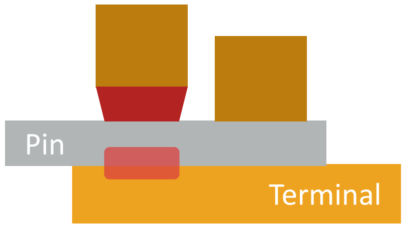
 **Low resistance electrode**

3. Electric Resistance Welding (ERW)

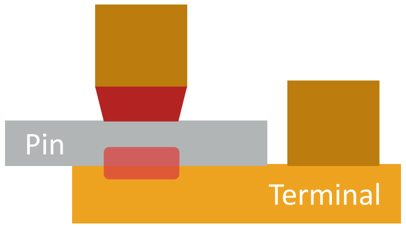
Common **one side** electrodes configurations for ERW

One side electrodes configuration can be used when there is not access to the bottom side of the terminal during welding

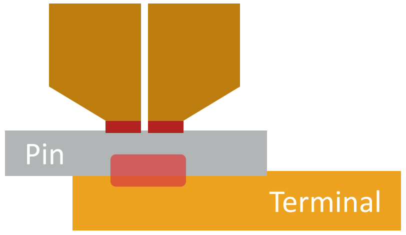
<u>No rework is allowed since it might lead to overheating of the mold body</u>



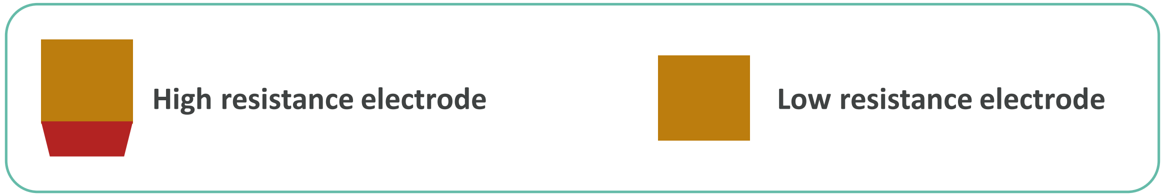
1 – Step welding of flat pin/terminal
Standard configuration



2 – Step welding of flat pin/terminal
Alternative configuration when the terminal is long



3 – Gap welding of flat pin/terminal
Preferred when the pins are short



3. Electric Resistance Welding (ERW)

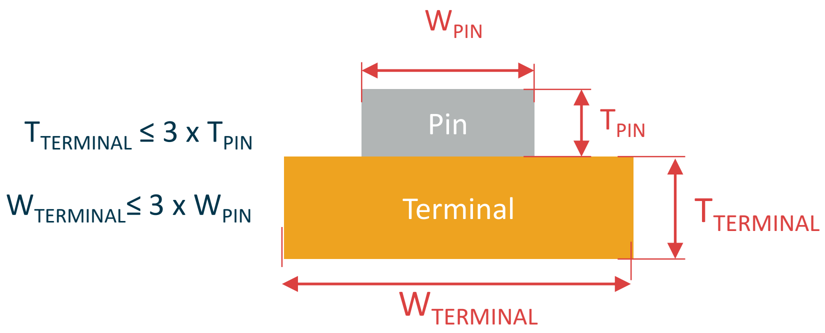
Housing terminal design for ERW

Care has to be taken to the degree of deformation of the IC pin so that resulting pin thickness is **<u>not less than 70%</u>** of the original one. Good welding results are achieved when a projection (fold) is formed on housing terminal, thus securing a high resistive contact between the two materials. A known working example is a radius of 1.25 mm for the bump.

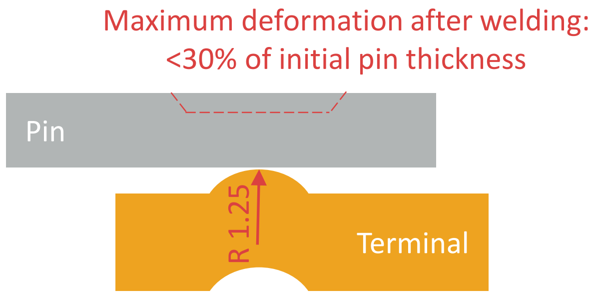
Housing terminal can be without any finish or with Sn or Ni. If Ni is used, electrodes might stick to the terminal during welding due to the higher melting point of Ni.

In case of Sn finish of the housing terminal, it's thickness shall not exceed 5um. Melexis pin finish is also electroplated Sn with a thickness of 7.5um to 15um, making the whole Sn thickness up to 20um. Due to the Sn low melting point, Sn ball splattering may occur.

Recommended dimensions of the housing terminal should be kept in the same ratio to pin dimensions as for LW.



FRONT VIEW

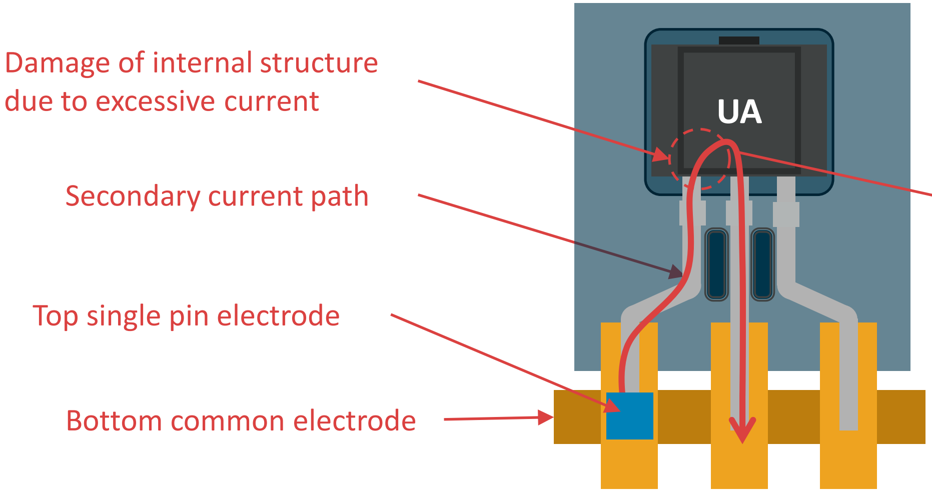


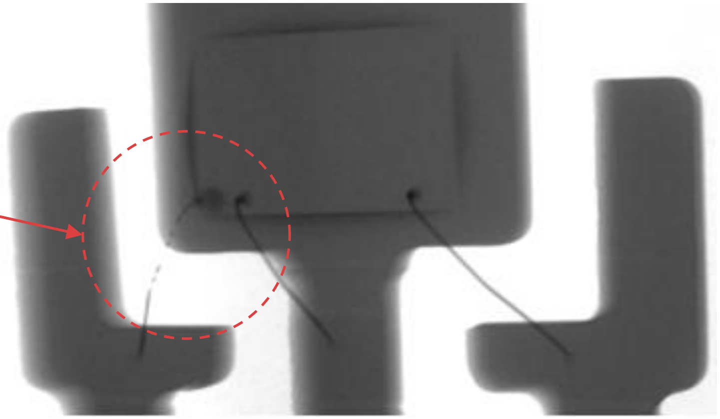
SIDE VIEW

3. Electric Resistance Welding (ERW)

Electrode configuration for ERW

Melexis recommends to have both ERW electrodes dimensioned for a single pin/terminal and weld pin-by-pin. Some subcontractors tend to design one of the electrodes contacting all pins to be welded, while the other is indexing. This may create a conductive path for a portion of the welding current through the internal IC structure, thus creating a risk of EOS (Electrical Over Stress), especially if welding voltage is close to forward diode voltage drop (usually >0.5 V). Due to the high currents used for ERW, even a small percentage of the total current might be sufficient for an irreversible damage of the IC.

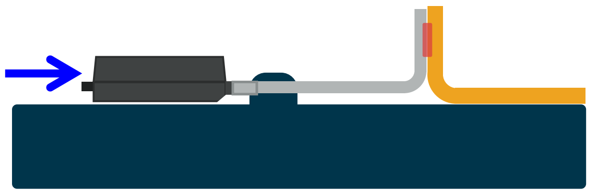


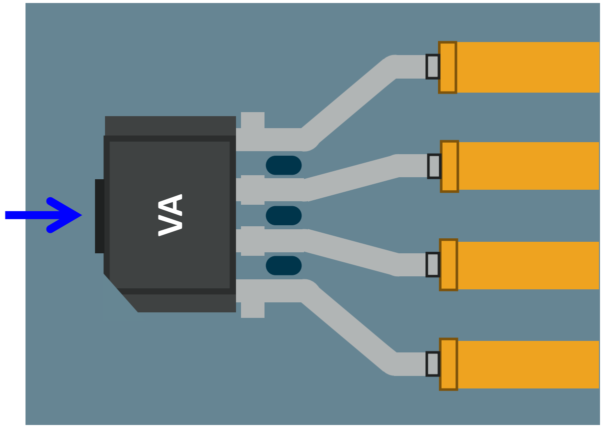


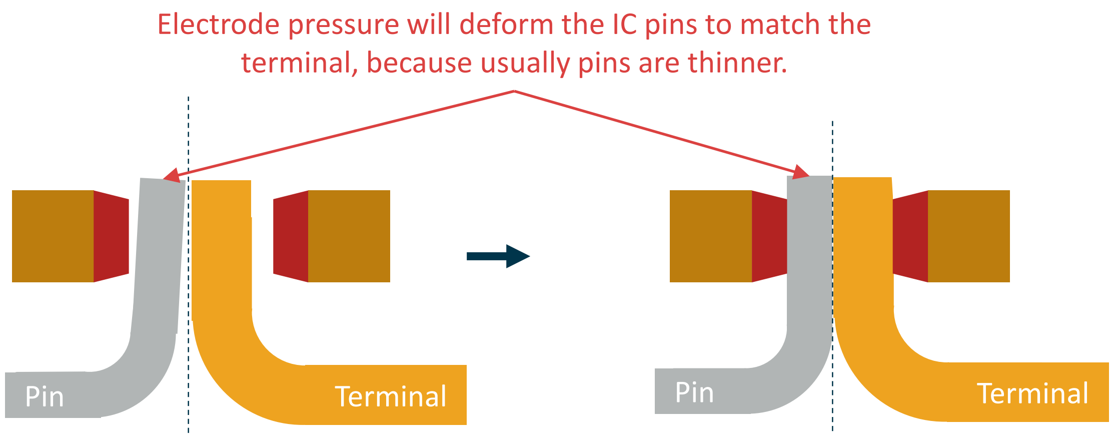
X-ray showing bond wire melted due to excessive current

3. Electric Resistance Welding (ERW)

Welding in L-shape terminals







If L-shape welding is foreseen, lead forming prior welding needs to be performed on the IC, please refer to *Guidelines for lead forming of Hall sensors in SIP package*.

While placing the IC into the housing, bent pins shall be brought in contact with vertical terminals by a sliding action, indicated by the blue arrow. This way a minimum deformation and pull stress on the pins during welding can be achieved

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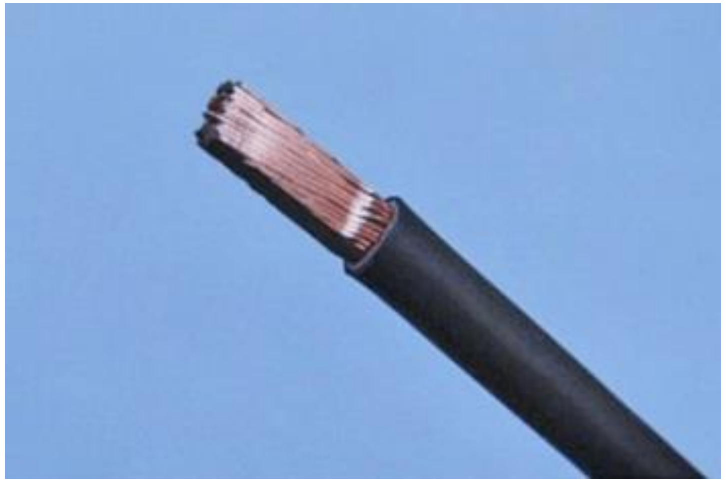
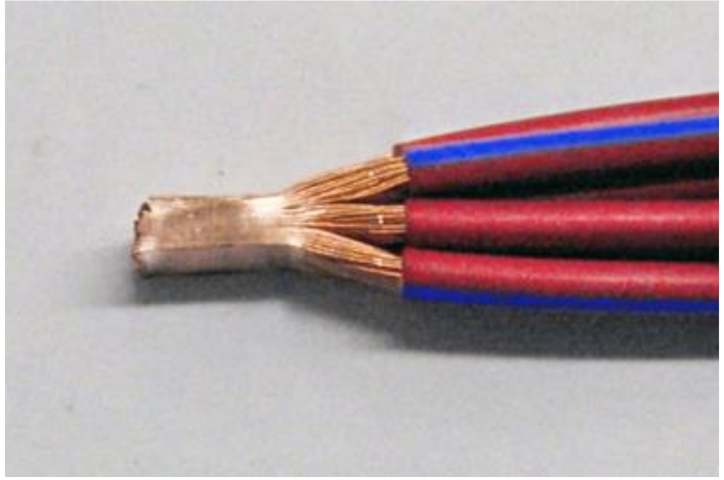
3. Electric Resistance Welding (ERW)

Cable strand welding - Welding IC pin to a wire

Melexis PCB-less device pins can be welded to a copper wire of size 0.5 mm^2 to 1 mm^2. The wire has to be flat (square). Therefore, it is strongly recommended to pre-weld - **compact** stranded (multi core) wires before welding, also known as strand welding.



Wire compacting



Compacting multiple wires

Pictures: Courtesy of Amada Weld Tech Inc.

Guidelines for welding of PCB-less devices

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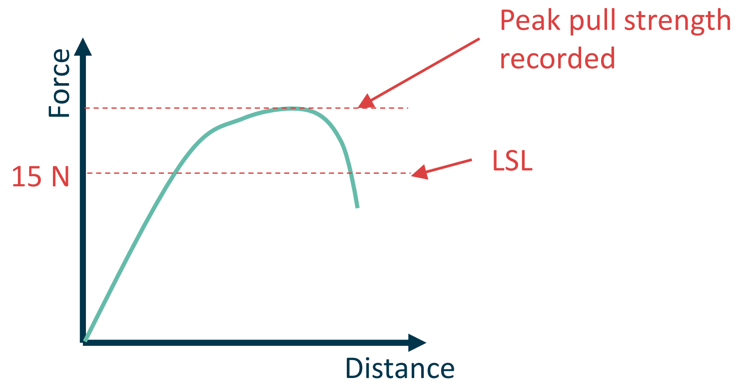
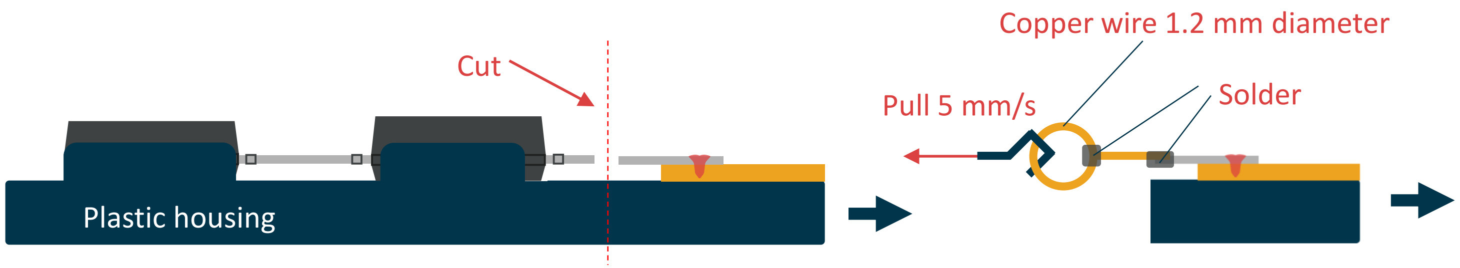
4. Inspection criteria

Criteria 1 – Welding joint tensile (pull) strength

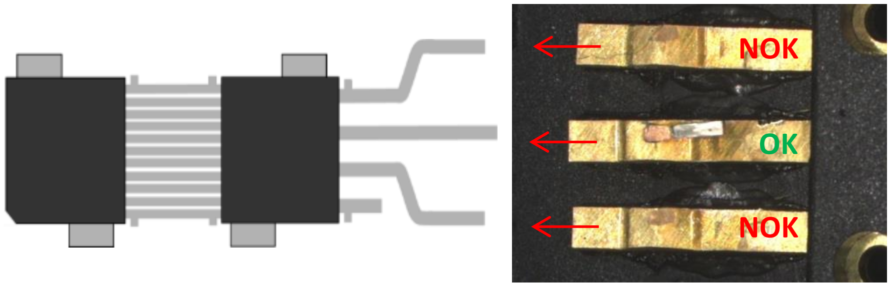
Welding tensile strength is established by a pin-by-pin pull test following the longitudinal pin axis. Pins are cut from the mold IC body, then pulled away from the welding joint. It is often needed to cut the plastic housing in order to have an access to the pins. To withstand thermal elongation and fatigue stress during thermal excursions in application, a welding tensile strength of minimum 15 N should be achieved. Acceptable failure mode is breaking of the pin at welding joint, while the welding joint remains on the terminal



Pull test graph and value acceptance criteria Fpeak > LSL



Example pull test setup



Pull test visual inspection accept/reject criteria

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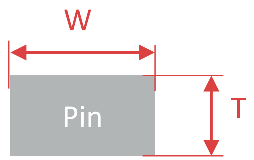
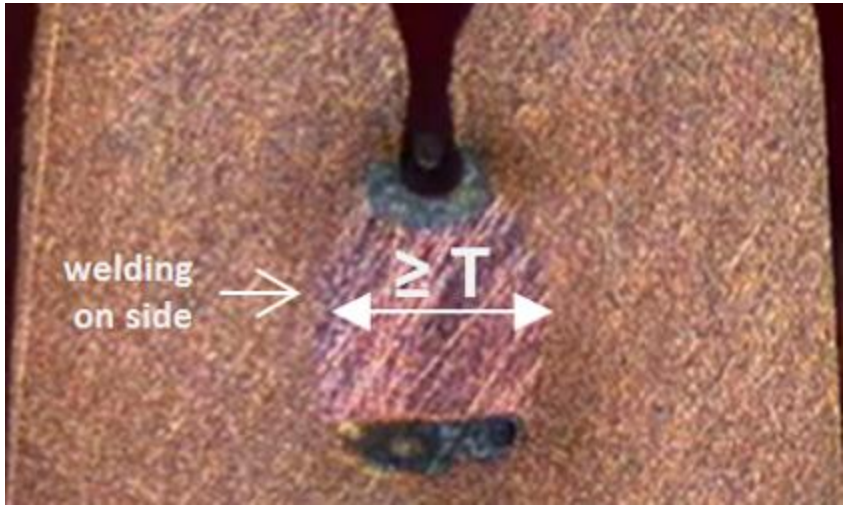
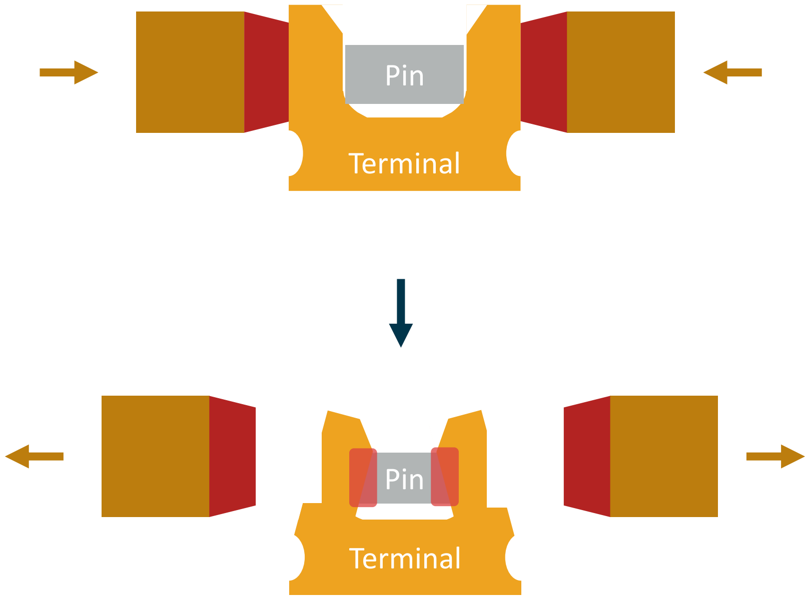
4. Inspection criteria

Criteria 2 – Cross-section of fork/butt welding

In fork/butt welding, the pin width will be deformed together with the fork terminal. A cross-section through the fork after welding is needed to verify that pin is consistently welded on the two sides and is not over-deformed (pinched). Remaining pin width W should be not less than the original pin thickness T.







Deformation of fork and pin after welding

4. Inspection criteria

Criteria 3 – Deformation of pin thickness after welding

Deformation of pin thickness should be limited to a maximum of 30% of the original value. Otherwise the reduced cross-section will reduce the strength of the welding joint.

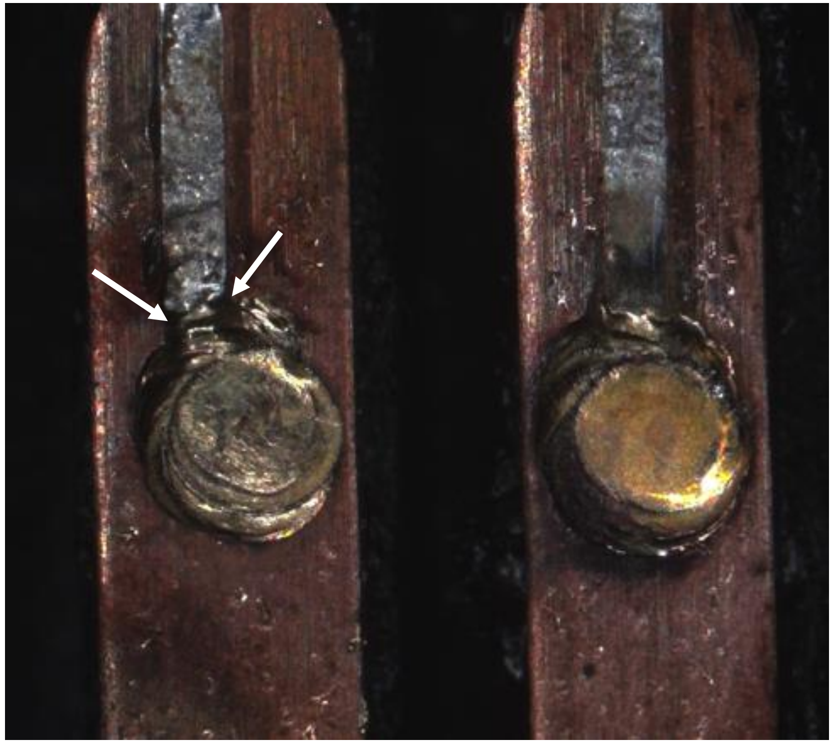
Guidelines for welding of PCB-less devices

5. Known pitfalls

Welding to a high reflective terminal (LW)

When welding to a high reflective base metal or finish,
there is a risk of IC pin over-melting due to higher energy absorption by the pin. This results in a weak link (necking), between the welding joint and the non-welded pin portion.

This can be avoided by laser pulse modulation or change of the terminal coating.



LW on uncoated copper terminal

5. Known pitfalls

Pin-to-terminal misplacement - Seam welding (LW)

Laser seem welding requires full pin to terminal overlap at the welding line.

If misplaced, a laser pin cutting will occur on the overhanging pin portion, resulting in a weaker welding joint.

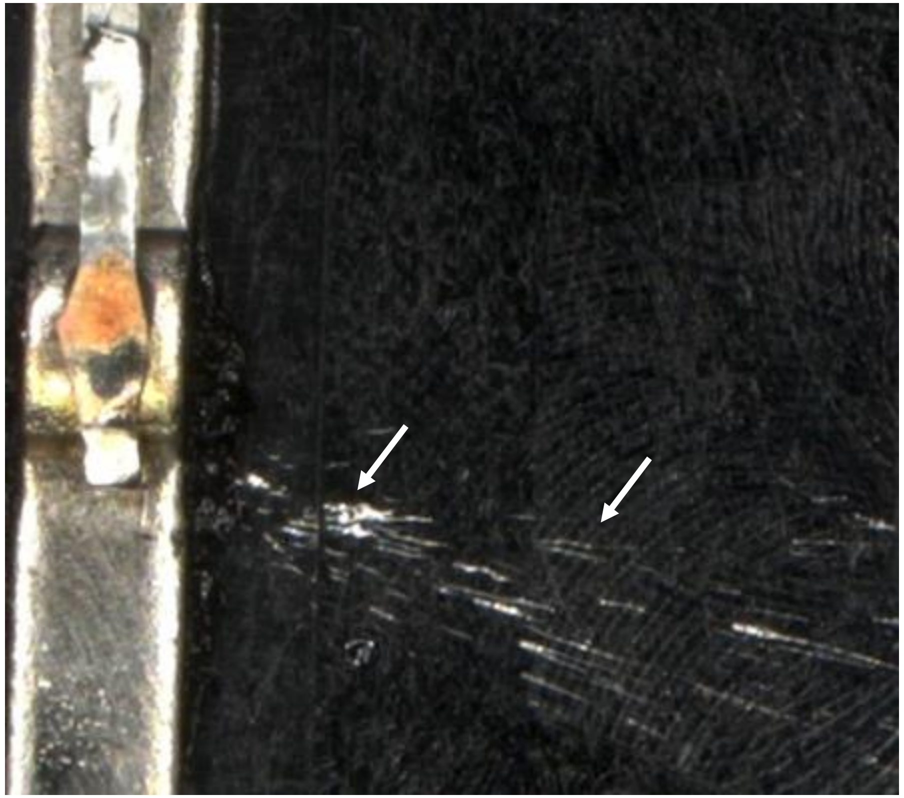
Cutting of pin with seam welding

5. Known pitfalls

Solder ball splattering (LW & ERW)

The leads of Melexis PCB-less have a surface finish of tin (Sn) with a thickness of up to 15um. These devices are intended for both soldering and welding. In order to keep parts solderable and avoid the risks associated with solder de-wetting, Melexis is following JEDEC minimum requirement of 7.5um Sn surface finish.

When welding to Sn plated terminals, the summed up Sn thickness and volume may lead to "solder ball splattering" effect. This in turn might lead to short circuit between two terminals. Therefore it is recommended to limit housing terminal Sn plating thickness to maximum 5um.



Solder ball splattering

5. Known pitfalls

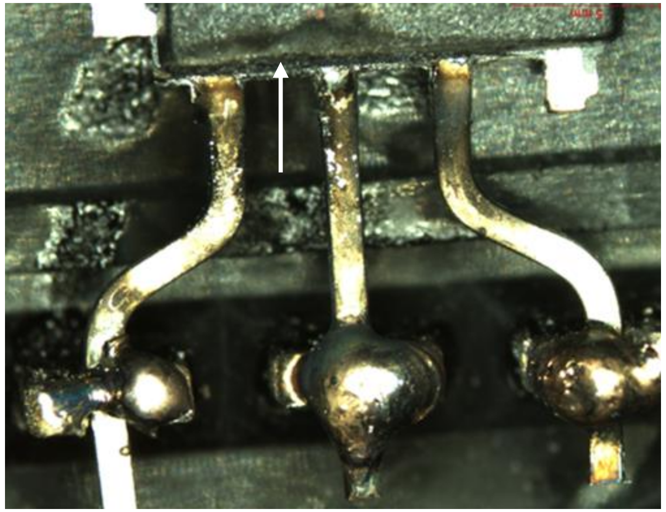
IC Overheating at fork welding (LW)

Laser welding of IC pin to a fork shaped terminal may require prolonged welding time due to:

- High and massive fork horns (top photo)
- Too large side clearance pin-to-fork horn
- Repeating lase welding in an attempt to rework

PCB-less device's mold package shall not be overheated above 270C during the welding process. Higher temperature may cause delamination and internal structural damage (bottom photo).

No rework of welding joints is allowed



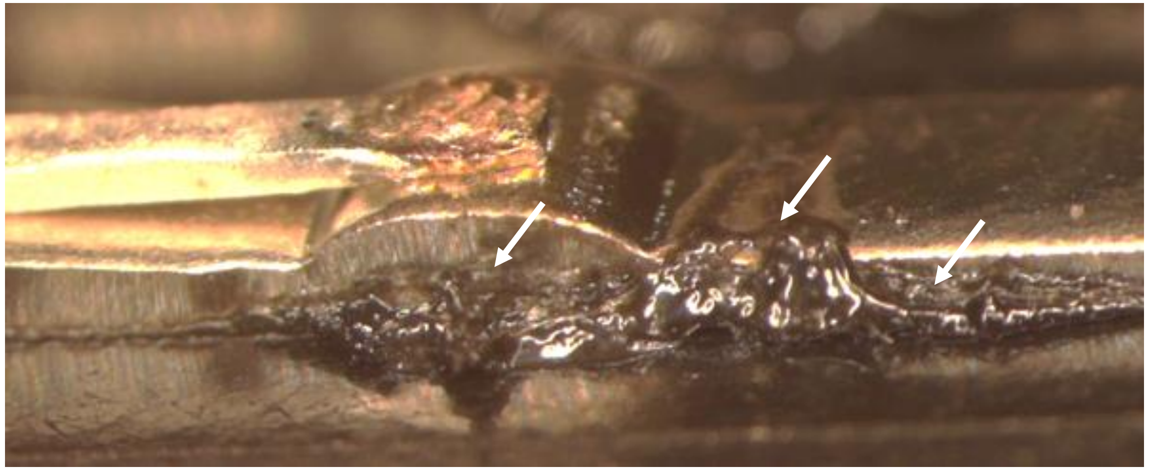
Overheating of mold package

5. Known pitfalls

Plastic melting and terminal collapse (ERW)

During ERW, electrode pressure and temperature may cause housing plastic melting next to the terminal. Sometimes the terminal will collapse into the molten plastic, leading to a weak welding joint.

This can be avoided by a proper terminal shape design limiting the heat dissipation into the housing plastic.



Housing plastic melting and terminal collapse

Annex I: List of Abbreviations

AMR: Absolute Maximum Rating
AN: Application Note
DMP: Dual Mold Package
EOS: Electrical Overstress
ERW: Electric Resistance Welding
IC: Integrated Circuit
LSL: Lower Specification Level
LW: Laser Welding
PCB: Printed Circuit Board
SIP: Single Inline Package
SMP: Single Mold Package

Annex II: List of Standards

J-STD-033: Handling, Packing, Shipping and Use of Moisture/Reflow Sensitive Surface Mount Devices

Annex III: List of Related Application Notes

Guidelines for storage and handling of plastic encapsulated ICs

Guidelines for lead forming of Hall sensors in SIP package.

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