microJoining Solutions – microTips™
5563 Hallowell Avenue • Arcadia, CA 91007
Phone: 626-444-9606 • Fax: 626-279-7450 • Email: mjs@microjoining.com • Web: www.microjoining.com

Laser and Resistance Welding and Selective Soldering - Thermal Loading Issues

By David Steinmeier

Thermal Loading
Thermal loading describes how two metal parts react to the heat generated within the parts for the purpose of creating a weld or solder joint. Thermal loading directly affects the success of all resistance and laser welding and selective soldering processes.

Heat Balancing
Heat balancing is the art and science of ensuring that the heat generated to melt or reflow solder the parts is greater than the heat dissipated by the parts. Consider the following simple statement:

Heat Generation > Heat Dissipation

There is a delicate balance between the rate and magnitude of heat generation and heat dissipation within the parts to be joined in order to produce a strong bond. Violating this delicate balance leads to poor bond strength. Excess heat generation causes material expulsion, voids, and embrittlement resulting in weak bonds. Insufficient heat generation or excessive heat dissipation causes inadequate melting between the parts, resulting in weak bonds.

Thermal Loading Factors
Material thermal conductivity, surface reflection and absorption characteristics (laser), input energy, parts geometry, and point of heat application affect the basic heat generation/dissipation equation.

Material Thermal Conductivity
The part material thermal conductivity determines how fast the bonding heat dissipates away from the heat source. Even though copper melts at 1083°C, it is much more difficult to weld than iron, which melts at 1,535°C. The copper dissipates the bonding heat ten times faster than iron. Successful copper to copper welding requires a high peak weld energy of a very short duration and a part geometry that helps to constrain the weld heat within the immediate bonding area.

Welding two thermally dissimilar materials such as copper and iron can also be challenging. The key to successfully welding this combination is to limit the copper's heat dissipation by controlling the copper part geometry.

Surface Reflection/Absorption (Laser)
All materials reflect and absorb incident energy at different wavelengths. To complicate matters, the degree of absorption changes as the material heats up. Surprisingly, some molten materials are more absorbent than solid, cool materials

Copper and aluminum are highly reflective compared to iron. To overcome the reflection barrier when laser welding with pulsed Nd:YAG lasers, some success has been achieved by using a high peak power pulse to begin the melting process, followed by lower peak power pulses to complete the weld.

Input Energy
Most stainless steels, for example, cannot be laser welded with more than 2kW of peak power. Copper and aluminum, on the other hand, require 3-5kW peak power to laser weld.

Part Geometry
Part geometry determines how much total bonding heat is required and how the bonding heat will be dissipated within each part. Geometry factors include: volume, parts overlap, parts gap, and point of heat generation in relation to geometry features such as the edge of the part.

Geometry Factor - Volume
Part shape and thickness determine part volume, hence partially determining how much total heat will be required to make a weld, braze, or solder joint. Thermal conductivity is the other factor contributing to the total heat requirement. The section *on Heat Balancing Techniques* explains how to mitigate the volume and thermal conductivity effects through the use of part shaping and "thermal island" design.

Geometry Factor - Parts Overlap
The degree of parts overlap affects both resistance and laser welding. If the parts overlap is small, then heat dissipation in each part is reduced, requiring less bonding heat.

Geometry Factor – Gap or Fit Up (Laser)
Gaps greater than 50 microns between parts 0.25 mm in thickness can severely affect weld strength and hermeticity when making a laser weld. The air gap impedes material flow between both parts and can cause material expulsion.

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Likewise, when selective soldering, a hot bar that warps when pulse heated prevents uniform heat conduction into the parts, thus producing solder voids in the gap areas.

Part Geometry Factor - Point of Heat Application
Applying bonding heat next to the edge of one or more parts can easily produce violent material expulsion. The source of bonding heat can come from the electrical weld current produced by the resistance welding process or by excessive peak power from a pulsed Nd:YAG laser.

Heat generated near a part edge can not easily dissipate through the part/air interface. Heat reflected back from this interface concentrates in the bonding area, rapidly raising the part temperature, resulting in material expulsion, cracking, and voids. Figure 1 shows the difference between parts laser welded using proper heat generation in relation to the part's edge and parts welded near the part's edge.

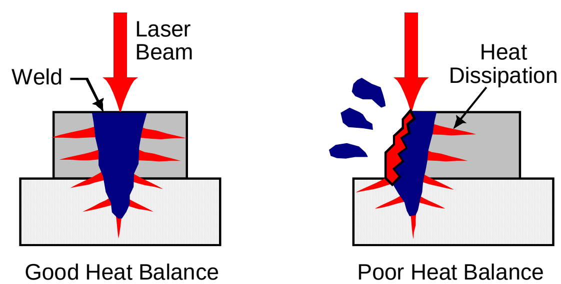

Figure 1 - Heat Application Edge Effects

Heat Balancing Techniques
Thermal loading problems caused by poor or uncontrolled parts overlap, gap, and edge heat generation can be easily corrected by the use of proper bonding fixtures.

However, thermal loading imbalances caused by thermal conductivity, volume, and parts shape problems can only be overcome by modifying part geometry. The misguided use of more bonding energy or time will not overcome a poor thermal loading situation.

Copper/Nickel Example
A 3 mm square by 0.25 mm thick nickel tab needs to be bonded to a copper block that is 10 mm square by 1 mm thick. Neither resistance nor laser welding will be able to impart sufficient energy to bring the copper block up to its melting temperature without first vaporizing the low thermal mass nickel tab.

One solution to this bonding problem is to use a low temperature brazing alloy or solder between the nickel and copper, then bring both parts and brazing alloy up to the brazing alloy's melting point in a brazing furnace, which acts like an infinite heat source to the copper block.

By modifying the copper block geometry to create a "thermal island" near the bonding interface a resistance or laser welding solution can be achieved. Figure 2 shows a cross section of how the copper block was stamped or machined to create a thermal island, thus restricting the heat dissipation from the bonding area.

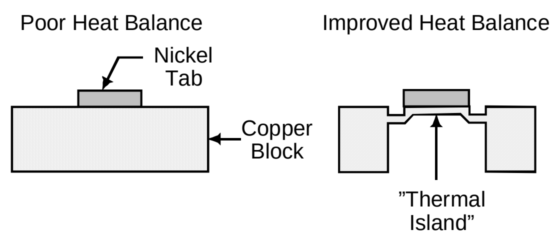

Figure 2 - Geometry Modifications

Flex-Printed Circuit Board Example
Many selective soldering applications involving flex to printed circuit board attachment suffer from poor thermal loading created by large ground plane connecting pads. The signal pads reflow nicely, but the ground plane pads suffer from cold solder joints due to heavy thermal loading. Figure 3 shows how the 'thermal island' solution can be effectively employed to solve the ground plane heat sinking problem.

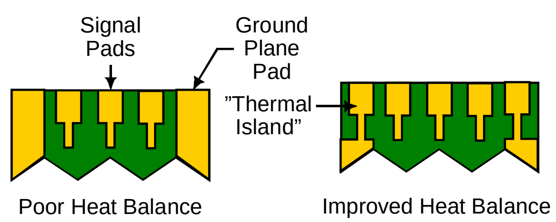

Figure 3 – Flex/PCB Geometry Modifications