Laser Solder Reflow: A Process Solution
Part II

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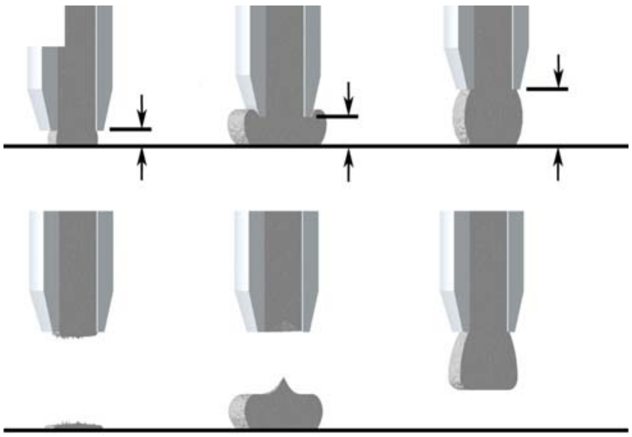
Abstract

With the use of laser light for reflow having been established, all that remains is to apply it to best effect. Each time a laser is fired, it pumps a specific amount of energy at a particular wavelength to a particular point in space. Where technique comes in is choosing where and for how long to apply that light along with the application of accessory equipment to optimize solder paste reflow. This presentation covers the specifics of how to determine which process choices are the right process choices based on the needs of your product to maximize yield and throughput.

Part Fixturing Considerations

The first requirement is finding a method to present or fixture the product to best facilitate both dispensing of solder paste and delivery of laser light. For the most consistent solder paste dispensing, each part needs to be located with the same relative position to the dispense tip in the Z axis. The distance from the bottom of the dispense tip needs to be between 1/4th and 1/6th the diameter of the deposit being made to ensure consistent release from the tip and to avoid blocking of the tip by hitting the product. If the gap is too small, the tip can be blocked. If the gap is too large, the paste can remain stuck to the dispense tip.

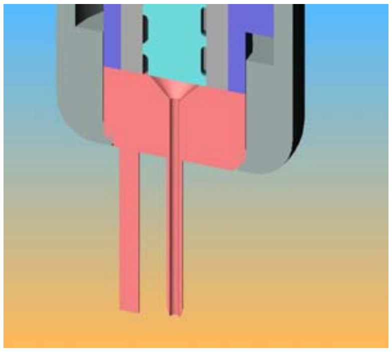


While laser focal distance is also critical, it is more tolerant with regard to variation in distance from lens to product. If laser light is off target due to X or Y positioning error, that area may overheat and be damaged. Conversely, solder paste can be dispensed partly off target in X and Y and it will coalesce back onto the joint area during reflow without damage to the product.

Process Consistency Concerns

The consistency of the solder paste dispensing process can be critical in the consistency of the heating process due to the amount of heat absorbed by the flux and alloy during reflow. If insufficient solder paste is present, overheating may result as less heat is devoted to flux evaporation and alloy liquefaction. If excessive solder paste is present, incomplete reflow may occur as there is not enough heat to reflow all the solder paste. Each product being different, there will be a range of solder paste deposit size over which the laser heating cycle produces perfect joints. On less thermally-sensitive products, it may be practically impossible to cause overheating due to lower solder paste volume. Each product must be evaluated to determine the optimal solder paste deposit size range and the controls required to achieve that goal.

For product designs that do not allow for a consistent physical target for dispense and laser reflow, the exactness of the laser can be a disadvantage. Excessive physical variation from part to part can result in inconsistent dispense volume and laser heating of the wrong spot. For example, if a wire on a terminal is the target, variation in wire location can cause variation in how the paste sticks to the part and whether the wire is adequately heated by the laser spot. Using a larger spot size can compensate for laser location inaccuracy to an extent. Vision correction can completely correct for physical misalignment and a footed dispensing system can compensate for inaccuracies in the Z axis.

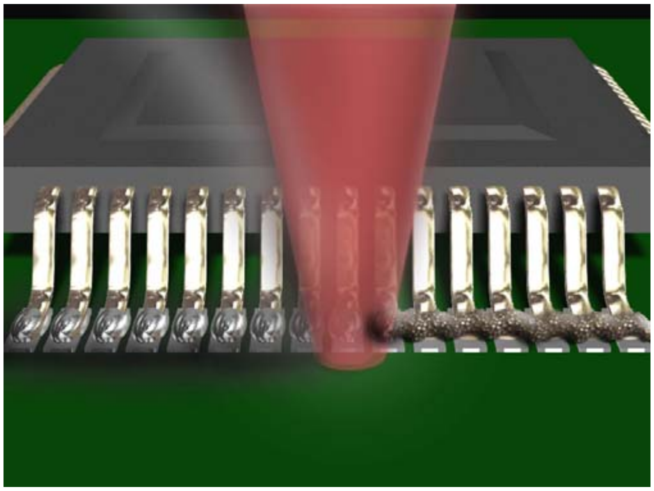


General Principles of Solder Paste Reflow

With all the methods described in this paper, we take advantage of one predictable property of liquid flux and solder. This is the tendency to become thinner and flow towards areas with higher temperature. As a fluid gets hotter, it gets thinner and spreads more readily. This causes it to preferentially flow towards points of heat. The closer it gets, the hotter it gets, the faster it flows.

Another property of most solder pastes is that about half of the flux can evaporate during reflow, the remaining flux is composed solids that will not evaporate These gasses are flammable and will ignite if overheated. They also slow the flux evaporation process by forming a super-saturated vapor layer above the joint. To maximize flux evaporation and minimize the chance of ignition, maintain a moderate to strong air flow across the area being reflowed. Proper venting will also protect the laser optics from possible flux redeposition as the hot flux vapor wafts and condenses about the cold laser optics.

The ability to vent flux vapor is critical for sub-second reflow times as the probability of vapor ignition is higher. Once the vapor carbonizes, turns to ash and falls onto the product surface, it absorbs a much higher percentage of the laser light because it is black. Parts covered with ash and exposed to laser light will rapidly overheat, burning temperature-sensitive materials such as circuit boards and plastics.



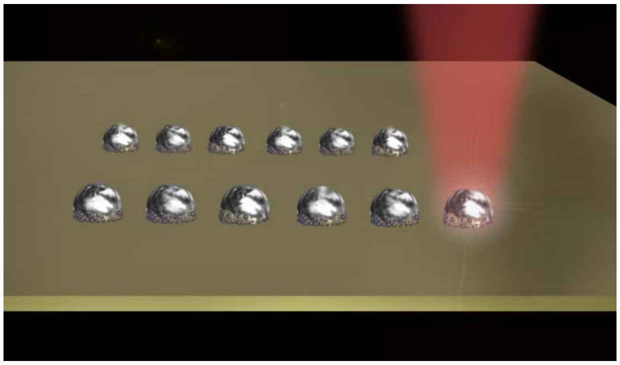
Where to Heat

The next question is where is the best spot to apply the laser light. The key features of lasers as a heating method is the non-contact, precision of location and amount of heat applied. The laser projects a consistent quantity of light at a point in space every time. Possible target choices include the solder paste deposit itself, a portion of the area to be soldered that is initially void of solder paste and a combination of the two.

In many applications, the paste will be dispensed upon the area to be soldered and the laser can be targeted at the solder paste itself. The laser light is absorbed by the flux and alloy, vaporizing portions of the flux, liquefying the alloy, and conducting heat through the molten metal to the surfaces to be soldered. This technique works well on relatively low thermal mass components and in close proximity to thermally-sensitive materials as conductive heat transfer to areas beyond the joint is minimized.

More thermally massive components, components that heat sink well, and larger areas need more heat to achieve wetting. With these types of parts, some or all of the laser focus must be applied to the components and/or substrate to achieve more uniform heating. There are two phenomena that can interfere with wetting if heat is not distributed properly:

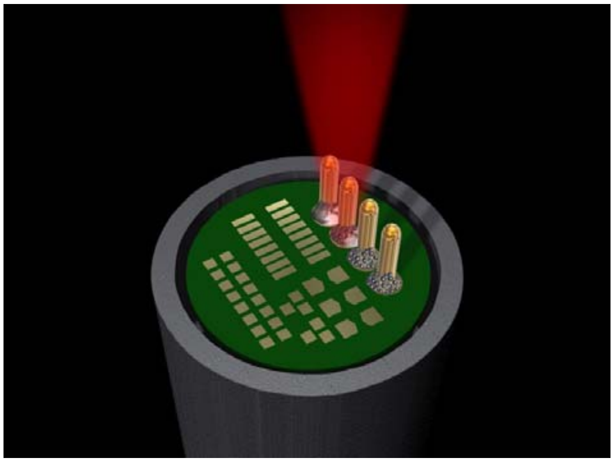
1. If all the heat is directed into the solder paste, the available flux can be fully consumed before the components reach reflow temperature and wetting starts.
2. The solder alloy can ball up on top of the components because they are not at a high enough temperature to wet out. In this case, the contact area becomes relatively small and the solder becomes a poor conductor of heat. The perfectly smooth molten solder sphere turns into more of a reflector than absorber and sends the laser light somewhere else.



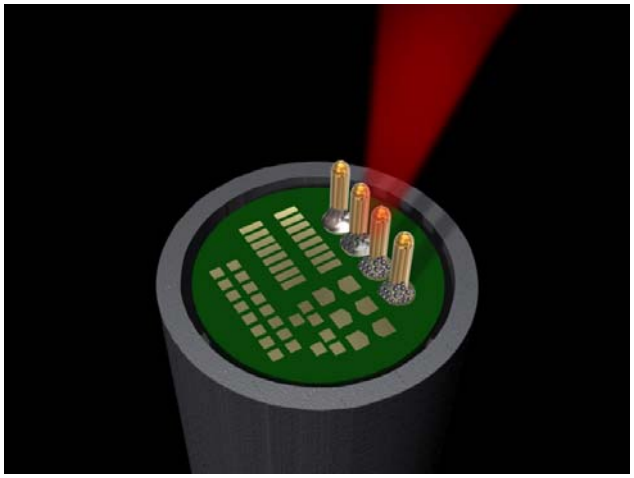
On some products, it is not practical to dispense solder paste everywhere it needs to spread. Applications like pin-in-hole where it is easier to dispense in one spot and heat the product in a way to make the solder paste wet completely around the pin are prime examples. The technique used for these types of joints will vary based on thermal mass and heat sensitivity of surrounding materials.

Most work well with one of two options:

1. Focus the laser spot to heat both the solder paste deposit and pin at same time. Reflow is rapid and the flux and alloy will readily wet down the through hole following the heated pin. This method is less reliable for large features as the far side of the through-hole will be at a lower temperature than the side focused on by the laser. It may be necessary to dispense on both sides of a pin in this case.



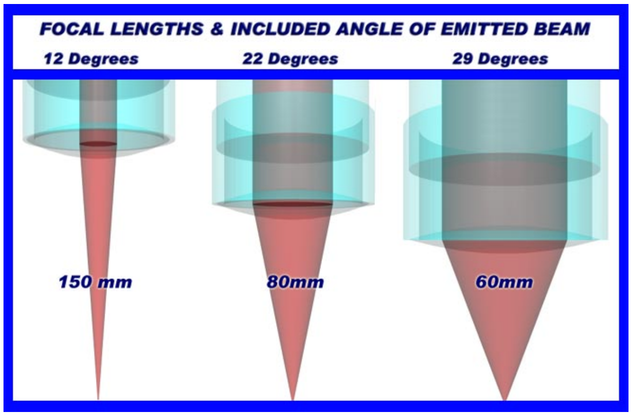
2. Focus the laser spot on the opposite side of the pin from the paste, heating the pin and annular ring. If the surrounding materials are too sensitive to overheating, this process will typically take longer as the heating rate must be slow enough to allow conduction to reflow the solder paste without damaging the surrounding material. The solder will reflow when the pin and ring achieve reflow temperature and run towards the area of highest temperature, where the laser light is focused.



Spot Size

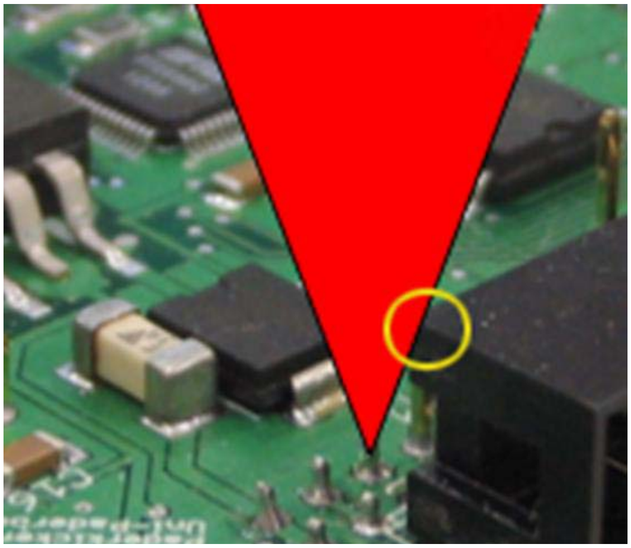
Spot size is a function of the optics used and the distance from the optics to the target point. In order to achieve more uniform heating over an area, a spot size of similar area may be used. If the spot is too small, all the heat is concentrated in one place and must spread through conduction. A larger spot can heat the entire area faster. A larger spot also keeps solder flow more uniform due to the absence of hot areas that might draw the flux and alloy as described in the section on General Principles Solder Paste Reflow.

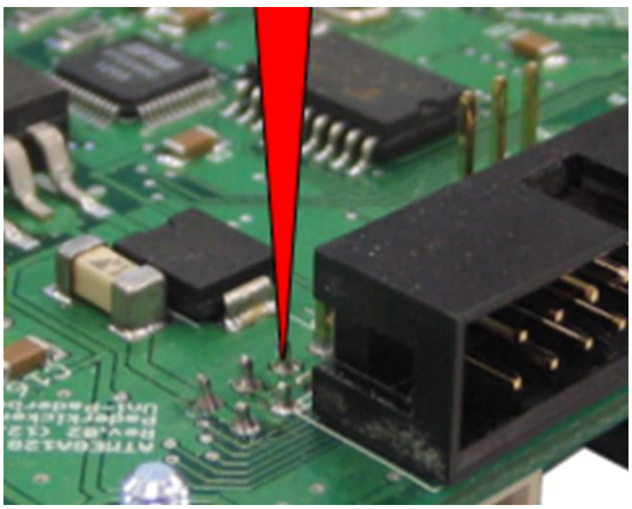
The minimum spot size can vary from 0.6 mm to 1.5 mm depending on the optics used. The smallest spot size is achieved with the shortest focal distance lens and becomes larger for lenses with longer focal distances. The spot size can be increased by adjusting Z-height of the optics head. With an increase of spot size, the energy is distributed over a larger area and the power output of laser system needs to be adjusted to maintain energy density. Another parameter that will vary with different end optics is the included angle of the cone-shaped laser light. The figure below shows a summary of the most commonly used focal lengths and their corresponding included angles.



The considerations for choosing end optics are as follows.

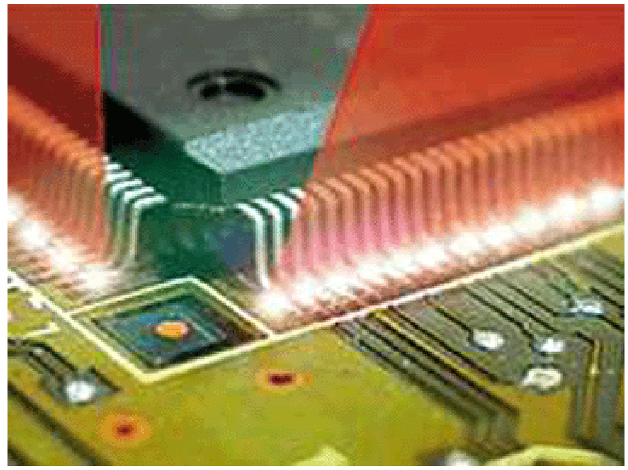
- **Size of the heated area:** For applications with small joint design it may be critical to maintain an adequately small spot size to keep laser energy off the area outside of the joint to avoid damage to the surrounding materials.
- **Clearance:** Applications that require the laser head to be mounted at certain height or angle to avoid bumping into the fixture or other objects need to use an end lens with appropriately long focal distance.
- **Tall components**: The laser light forms conical shape, therefore when soldering near tall components some clipping may occur. Choosing optics with smaller included angle may be necessary.



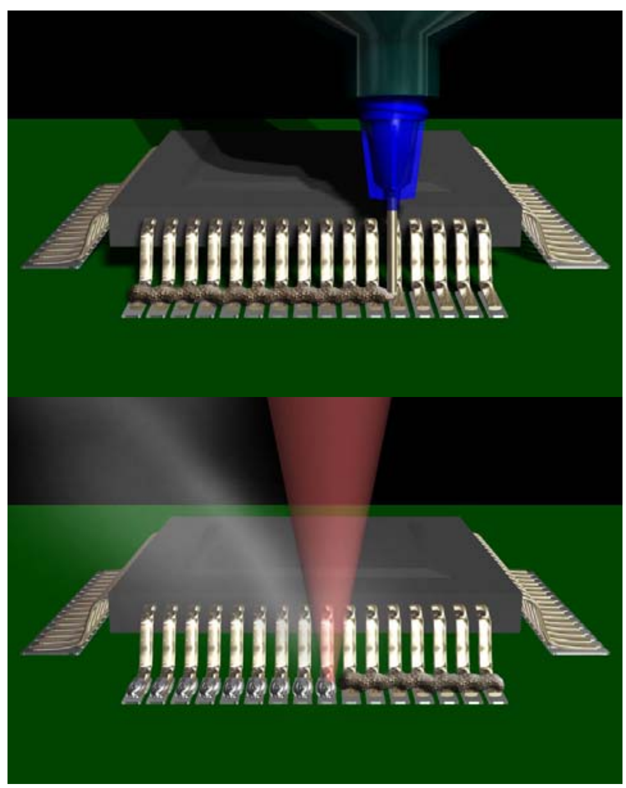


Line Soldering
So far, only point-to-point heating has been addressed. Of equal and sometimes greater usefulness is line heating. There are two methods for line heating. In one method, the point of focus is moved across the area or row of points to be reflowed. In the other method, the laser light is shaped into a line by special optic. The advantage to such an optic is that the entire area can reflow at once and may be faster than the moving spot technique. The laser line formed by standard optics is 25mm wide.

Applications requiring reflow over longer distances will need to be processed in a number of steps. Laser systems with a line module capable of providing up to 90mm wide line are also available. The disadvantage is that line optic or line module is limited to line reflow applications. For products with a variety of heating areas, the dedicated line optic together with a separate laser system are required in addition to a laser system with a spot optic.



One example of moving the point of focus is a Quad Flat Pack (QFP), SOIC, ribbon cable or other component with many terminations on a side. Solder is dispensed in a line across all the pads. The laser follows the same path. Each location goes through a mini reflow profile as the spot traverses the area. Solder is reflowed incrementally, forcing it to coalesce and draw back to each wettable point as it passes. Heating rate and total laser exposure time is a function of spot size and velocity. For this method to be viable, the material in between wettable points must not absorb so much light that it is damaged. Typically, the solder paste absorbs almost all the light, protecting the circuit board or other material in between.



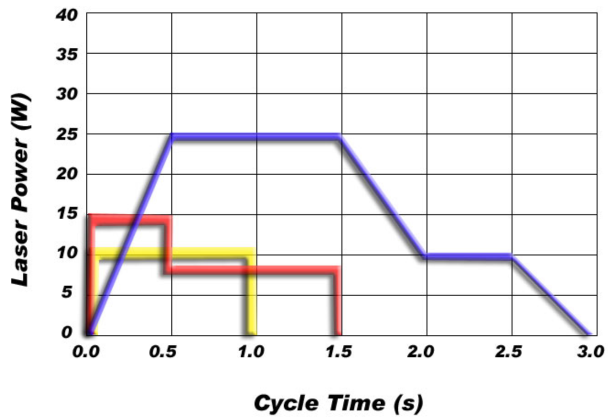
Reflow Timing

As has just been implied, sometimes the full power of the laser cannot be used. There is a practical limit of around ¼ second of heating time for even the most ideal laser soldering applications because it takes time for all the surfaces to heat the alloy to spread. Most point-to-point laser reflow applications will have laser on-time between ½ and 2 seconds. The controlling factors are:

- **Thermal load of components:** More massive parts heat slower. Parts with high thermal conductivity act as heat sinks.
- **Mass of solder paste:** The laser must add enough energy to vaporize flux and liquefy alloy. Flux vapor affects heating rate and can auto-ignite.
- **Distance to wet:** The farther it has to flow, the longer it will take. Alloy must remain liquid long enough for it to finish flowing across surfaces and wetting.
- **Joint geometry:** Complex geometries like stranded wires take longer for alloy to wet out fully. Alloy must remain liquid long enough for it to finish flowing across surfaces and wetting.
- **Thermal sensitivity:** Parts and solder must be heated fast enough to limit total heat absorbed. Excess heat may conduct to and damage nearby materials.

Because lasers can control energy output in timed segments, heating can be profiled to take best advantage of the heating effects required. For simple point-to-point heating with no special considerations, a profile might be a single power level for a time. If cycle time is at a premium and parts need a minimum amount of time to fully wet, the laser could fire at a higher power level long enough to initiate reflow before dropping to a lower power to keep the area heated enough to maintain reflow without overheating.

Power level can also be changed linearly over time, ramping from one output level to another. With all these power profiling options available, it is just a matter of testing to determine which gives the best performance.



Conclusions

A diode laser is a precision tool. In combination with solder paste, it can be used to form solder joints using a wide variety of techniques based on the thermal requirements of a product. Misapplication of laser energy is a good way to burn parts, much like with other heating methods. By creating a reflow environment that takes advantage of the characteristics of laser energy deliver and absorption, along with the reflow characteristics of solder paste, very difficult soldering tasks can be performed with high first-pass yields.

Performing sample reflow tests is a proven methodology to identify whether laser reflow is suitable to a product and the process variables that must be controlled to produce the desired solder joint. A theoretical analysis of how lasers are likely to perform is one thing but practical application is another. If laser reflow of solder paste is identified as a viable method for a product, work with the solder paste vendor and laser system supplier to identify the optimal combination material and equipment for the product.