Optimization on laser soldering parameters onto lead-free solder joint

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Abstract. This paper presents the results of optimization on laser soldering parameters onto lead free solder joint. The objective of this study is to determine the laser power needed and scanning time required to produce a high quality of solder joint. Laser soldering was selected due to its rapid and controllable selective process as well as suitable for temperature sensitive assemblies, which is very desirable nowadays as compared to time consuming process such as casting. A fibre laser with 200W was used in this study to form a joining between lead free solder wire and copper board. However, a continuous laser power was ranged between 48 to 60W to create joining. Before that, flux was also applied prior to laser soldering for uniform heat distribution throughout the solder volume. Lead free solder wire with the size of 1.0mm diameter was formed into several shapes including straight line-shape with 20mm in length, and spiral-shape with 6mm diameter, in order to capture and disperse the heat evenly. Results showed that laser power ranged from 48W to 60W with 3.5 to 4.5s duration was found to be suitable for lead free solder wire with spiral-shape condition. Besides, the wetting angle was also in optimal when the laser power was increased. The optimized fibre laser parameters obtained in this study will be used for future reference in performing a laser soldering between solder alloy copper board.

1. Introduction

Due to the environmental and health concerns, Sn-Pb solders have been banned and the studies on lead-free solder have been done world widely in conjunction of supporting Waste Electrical and Electronic Equipment (WEEE) and Restriction of the Use of Hazardous Substances in Electrical and Electronic Equipment (RoHS Directive) [1-3]. Lead-free solder such as Sn-Cu solder alloys are seen as one of great potential substitute of Sn-Pb solder alloys due to its good wettability, high electrical conductivity, good mechanical properties and economically costing [4-6]. Furthermore, Cu has high availability, good electrical and thermal conductivity, therefore it has always been chosen for any metallization layers medium in the manufacturing of electrical components [7, 8].

Laser soldering technology is known to have been used since many years before due to its highly advanced selective soldering whereas the heat is applied only on the desired spot, mechanically controlled by the machine and thus result in high production rate [2, 8, 9]. Meanwhile, as to compare with conventional method which is reflow soldering, the laser soldering has contactless temperature measurement during laser process and rapid rise and fall temperature cycles that will certainly minimize the thermal damage especially for heat-sensitive components [10, 11]. It is also been claim that soldering by using laser technology produce a good electrical conductivity in the integrated circuits assembly and void defects are minimized due to it’s fast evaporation of flux [1, 12]. Therefore, laser soldering technology has been quite well-known of its advantages in electronic packaging industries however the study on its optimal parameters are still ongoing.
However, finding the optimal laser parameters is difficult as the heat diffusion from solder to surrounding parts and beam reflection are unclear. For human work, they are able to control the heating by visual confirmation for precise soldering. However, laser soldering is completely mechanically controlled by the machine [8]. Meanwhile, if the rate of heating is too intensive and surpass the required temperature for the solder to melt, it may cause some deterioration to the materials surrounding, nearest components and layer surface and thus affects the electrical flow performance but when insufficient output power is applied, the solder itself may not be melt [2, 13]. Thus, it is essential to find the optimal laser parameters such as the laser output power and irradiation time in order to gain good joints and avoid unexpected complication later [13, 14].

Therefore, in this study, we performed some experiments about laser soldering in order to find the optimal parameters of lead free solder joint. In the experiment two types of shape which are straight line-shape and spiral-shape were used, in order to capture and disperse the heat evenly. Then, we discussed the solder shape dependence on heat absorption and the effects of different parameters on the wettability joint.

2. Experimental Procedure

Lead free solder wire (diameter of 1.0 mm), SnCu was used in the experiment. The solder wire was cut in straight line shape with 20mm in length and was placed on the printed copper board (PCB) manually (Figure 2 (a)). The PCB was clean first by using ultrasonic cleaner with ethanol as the cleansing solution. A thin layer of Kester TSF-6522RH rosin based flux was applied on the PCB. After the solder wire was placed on the PCB, a thin layer of flux was lightly applied again on top of the solder wire. The laser device used in this experiment was a continuous wave type fiber laser (Figure 1). The laser parameters such as the output power and irradiation time were computer-controlled. The output power of the laser used are in range of between 48W to 60W and for the irradiation time it was varied to 3.5s, 4.0s and 4.5s. The PCB then are placed on the x-y platform jig as shown in Fig 1. The procedures are then repeated for spiral-shape with 6mm diameter solder wire (Figure 2 (b)).

After laser soldering, the samples were observed physically. The mechanical properties that were observed such as the joining between the solder and the PCB and the wetting angle performances.

![Figure 1. The illustration of experimental apparatus.](image-url)
3. Results and Discussion

3.1. Effect of solder wire shape on the solder joint

Figure 3 and Figure 4 show the photos of top views of the solder wire that has been soldered by using the laser with different laser output power. When using a 50W laser power heating time for 3.5s, it was observed that the solder was not joint on the pad for a straight-line solder wire shaped (Figure 3 (a)). Meanwhile, when the power was increased to 55W and 60W, it could be seen that, the solder did create joint with the pad (Figure 3 (b) and (c)). However, the surface wetting for both joint were no good and the solders were almost burned. When the power is increased, the solder joint increased however, at a certain power output, the heat might be too much and caused burned on the solder.

Figure 3. The top views of straight-line in shaped solder wire, laser heating time of 3.5s and laser output power of (a) 50W, (b) 55W and (c) 60W.

For the spiral in shaped solder wire, the solder did create a joining when the laser output was ranged in between 48W to 60W and irradiation time of 3.5s. As it can be seen, as the power output was increased (from left to right) the area of the solder that are soldered was increased. Good joining between the solder and the substrate interface could be gained, when larger contact area are created on them [15]. Furthermore, the spiral-shape solder has a larger volume of solder compared to a straight-line shape solder. The heat are able to disperse evenly before it solidifies completely when volume is increased. Therefore, the larger contact area between solder/surface and volume of solder are some factors that affect a solder joint.
3.2. Effect of different laser parameters on the wettability of solder joint

Wettability of solder joint plays an important role in the manufacturing of electrical components as it is the measurement ability for the molten solder to make interconnection between solder and substrate [16, 17]. The acceptable contact angle range should be below 45º and the smaller the contact angle the better is its wettability joint [18]. In Figure 5 shows the wetting angle of spherical-shape lead-free solder wire with irradiation time of 4s and different laser power output range in between 48W to 60W. The wetting angle was decreases as the laser power output increasing from 48W to 52W. However, the wetting angle starts to increases from 54W to 60W of laser power output. It can be said, that the optimal wetting angle was found in between range of 52W to 60W power output.

![Figure 4](image-url)  
**Figure 4.** The top views of spiral in shaped solder wire, laser heating time of 3.5s and laser outputpower of (a) 48W, (b) 50W, (c) 52W, (d) 54W, (e) 56W, (f) 58W and (g) 60W.

![Figure 5](image-url)  
**Figure 5.** The relationship between wetting angle (º) and the laser power (W) for spherical-shape lead-free solder wire.

Figure 6 shows the wetting angle of spherical-shaped lead-free solder when the laser power output was fixed for 52W and the irradiation times were varied from 3.5s to 4.5s. When the irradiation time is 3.5s, the wetting angle, 44.1º was near to the optimal range of wetting angle as mentioned before. However, for 4s irradiation time, the solder molten can be seen to be more flatten compared to the others with wetting angle of 19.4º. At 4.5s irradiation time, the wetting angle increases again up to 37.6º, but still in optimal range as claimed from previous studies. For all three solders, it shows that the wetting angle gained are still in the range of good wetting angle which is below 45º.
Figure 6. The wetting angle for spherical-shaped lead free solder wire with laser power output of 52W and irradiation time of (a) 3.5s, (b) 4s and (c) 4.5s.

It is shown here, the wetting areas of solder on pads were getting larger as the output laser power is increase. As the output laser power increased, the area of solder to melt getting larger plus the contact areas between the solder and the surface of the substrate increased correspondingly making the solder spherical shape to disappear slowly and become more flatten, thus larger wetting areas are gained [19]. Meanwhile, when the irradiation time for solder is insufficient, the solder molten solidified faster and gives out not enough time for solder to disperse more on the surface of substrate thus making the wetting angle decreases. Therefore, in order to achieve an acceptable wetting, a balance between power output and heating time is inevitable.

4. Conclusion
In this study, it can be concluded that:

i. The contact area and the volume of the solder affects the rate of joining between the solder and substrate. The larger the contact area, the better the solder to joint. As in this study, the spherical-shape lead-free solder wire results in better joining compared to the straight-line shape lead-free solder wire.

ii. The increases of power output, increases the wettability joint of solder. However, a balance of controlling the power output and irradiation time parameters should be taken in account in order to obtain a good wettability joint.

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