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Effect of Laser Loop on Surface Morphology of Copper Substrate and Wettability of Solder Joint

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Abstract. The effect of different laser loop parameter on the geometry of micro-groove pattern on copper substrate and its effect on the wettability was investigated. The micro-grooves pattern was fabricated on the copper surface through laser surface texturing process. 3D measuring laser microscope and contact angle measurement test was conducted to measure the geometry of the micro-grooves pattern and wettability of the solder joint respectively. The results showed that the improvement in laser loop parameter increased the depth of the micro-grooves due to the more exposed time which allows more material ablation. It also showed that the contact angle of textured substrate is smaller than the untextured substrate which results in better wettability.

1 Introduction

Surface texturing is one of the current growing concerns in the materials industry, which involves modifying the surface characteristics resulting in an enhancement in the material's performance. The arrays of patterns can be either micro-scale, nano-scale, or its combination. Textured surfaces provide improved tribological, biological, optical or wetting characteristics after tailoring of the texture for specific purposes. The textured surface has gained considerable interest due to its excellent performance and its use as an anti-reflection, anti-fouling, anti-corrosion, low surface energy surface and self-cleaning material [1–4].

As the interest in tribological effects of surface texturing increases, various methods has been developed over the decades to fabricate surface textures. At a very early age, etching technique was once used to produce a physical textured sample for the purpose of analysing the most efficient parameters discovered from theoretical analysis [5]. Vibro-rolling method, where a hard indenter was used to produce shallow grooves on metallic parts, was later developed by Schneider [6]. Due to technological advancement in the past decades, the techniques of surface texturing was improved. Other surface texturing techniques include

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laser surface texturing, reactive ion etching, lithography and anisotropic etching and micro-casting [7–11].

Throughout the years, laser surface texturing (LST) has emerged as a viable means in research study as it is one of the most advanced surface texturing techniques in producing micro-textured patterns and enhanced the tribological performance and biomedical applications. The laser used is extremely fast which allows short processing times. It also provides high precision control of the size and shape of the geometrical parameters to generate holes and complex shapes on a wide range of materials including metals, ceramics and polymers [12–13].

Laser surface texturing (LST) is a process to generate periodic micro or nano or micro/nano structures which involves very thin layer of material surface. LST is usually used to enhance the tribological performance of a mechanical component or create functional surfaces for certain applications. This process is applied in the tribology [14–16], biomedical [17] and optical fields [18] as it offers great surface wettability and high adhesion strength for the material parts [17–20].

Wettability is one of the criteria that contribute to the reliability. It is defined as the bond between the solder and the base metal is formed only when the solder wets the base metal properly. Solder wettability is determined from contact angle (°) to the copper (Cu) substrate. The smaller of contact angle, the better wettability of the solder interconnection [21]. To create reliable joint, it is necessary to reach good wettability on contact pads as well as on component. Smaller wetting angle will cause the excellent wetting. Measurement of the wetting angle is the easiest way to characterize a wetting process. Wetting angle depends on several important factor such as solder alloy, flux, and surface roughness [22].

This present study focuses to evaluate the effect of laser loop on surface morphology of copper substrate and wettability of solder joint. The effect of laser loop on the microstructure of the micro-groove on the surface of copper substrate is analysed using 3D measuring laser microscope to evaluate the surface profiles. The wettability of the solder joint on the non-textured and textured copper substrate were investigated using optical microscope and J-image software.

2 Experimental

The micro patterned surface of copper substrate was produced through laser ablation to verify the structure geometry and contact angle. The effects of laser loop on the micro-texture dimension of samples will also be studied.

2.1 Material details and pattern design

A flat square-shaped copper sheet specimens are used in this research. Each specimen has a dimension of 15 mm × 15mm × 1 mm. The specimens were ground using 1000-grit sandpaper and then polished with 1 µm alumina diamond polishing paste.

2.2 Laser surface texturing

A micro-groove texture was developed on the polished copper surface by using a laser surface modification technique. The Ytterbium Fiber Laser Marking Machine was used to produce the closed-pore type texture, with a fixed groove distance of 100 µm. A laser beam with a size of approximately 50 µm was introduced directly to the copper substrate surface using different parameter of laser loop. The loop (L) varies from Loop 1 to Loop 4 for the specimens. But for each specimen, the main parameter was fixed and shown in Table 1.

Table 1: Laser surface texturing parameters.

Parameter	Value
Name	Ytterbium Fiber Laser Marking Machine
Model	ML-MF-A01
Wavelength (nm)	1064
Scanning speed (mm/s)	300
Laser power (W)	18
Repetition rate (KHz)	20

2.3 Reflow soldering

The solder alloy, Sn-0.7Cu ingots which was supplied from Nihon Superior Co Ltd., Japan, was used as solder material. The solder alloy was prepared by melting the ingots at a temperature of 350°C in a solder pot. The ingot was then cold roll to produce thin solder sheets. The thin solder sheet was cut and then divided into approximately 0.5 g using a weighing balance. The 0.5 g of Sn-0.7Cu was then reflowed onto micro-textured Cu-substrates in a F4N reflow oven in making the solder joints with the aid of small amount of resin mildly activated (RMA) flux.

2.4 Characterisation and testing of samples

The microstructural characteristics of the textured copper substrates was observed using 3D measuring laser microscope model Olympus OLS5000. The wettability of the solder alloy on micro-textured substrate was then observed by measuring the contact angle of the solder joint using optical microscope and Image-J software.

3 Results and discussion

3.1 Analysis of surface morphology

Laser surface texturing is a localized thermal process where the material will absorb the laser beam energy and results in material ablation. This process will then change the surface morphology and topography of the material involved. The dimensions of the micro-groove on the copper substrates differ with the laser loop parameter. The 2D images of the surface morphology and profiles of the micro-groove copper substrates for laser loop 1 is shown in Fig. ***1***(a) and Fig respectively. When the laser beam in contact with the copper substrate, the material will absorb the laser energy which will heated the material up and then evaporated. This process is called as laser ablation which means that the part that are in contact with the laser beam are going to be removed. In this case, the micro-groove are formed via the laser surface texturing process where the depth of the micro-groove depends on the laser loop parameter. Based on the figure, the average depth of the micro-grooves of laser loop 1 is around the range of 2-4 μm. The depth of the micro-grooves of laser loop 1 of the copper substrate is small due to the short exposed time of the material to the laser beam.

As we can see in Fig. ***1***(b) and Fig, the average depth of the micro-groove formed by using laser loop 2 is in the range of 6-8 μm. The depth of the micro-groove of laser loop 2 is increased compared to the laser loop 1. This is due to the copper substrate of laser loop 2 absorb more laser energy which gave the material to melt and evaporates more compared to loop 1.

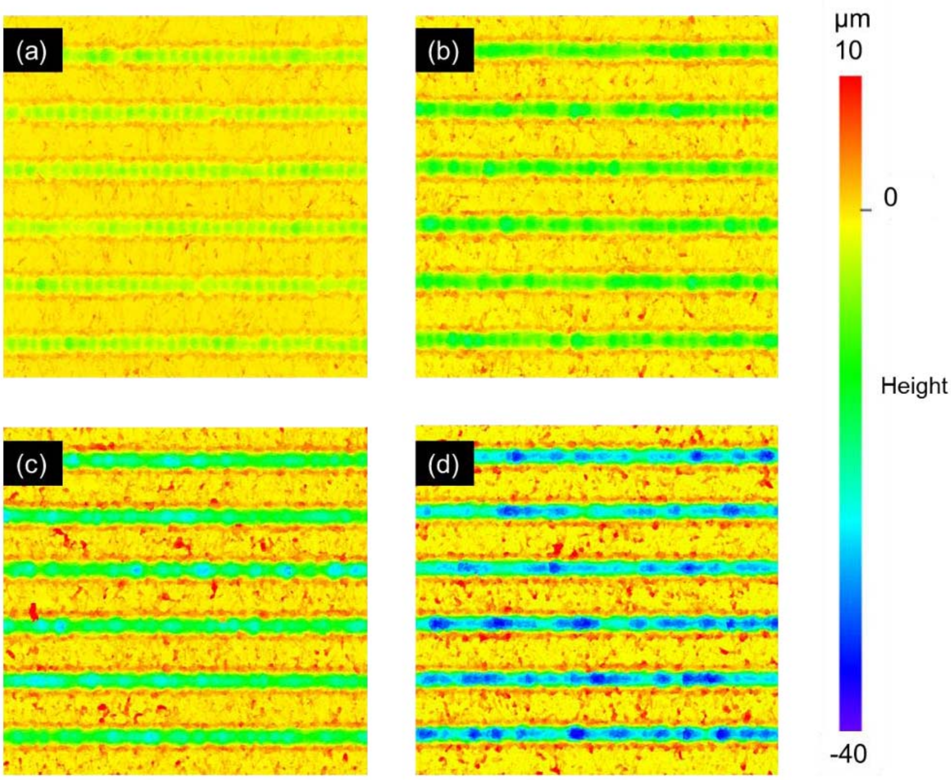

Fig. 1. 2D images of copper substrate of ; a) Loop 1, b) Loop 2, c) Loop 3 and d) Loop 4.

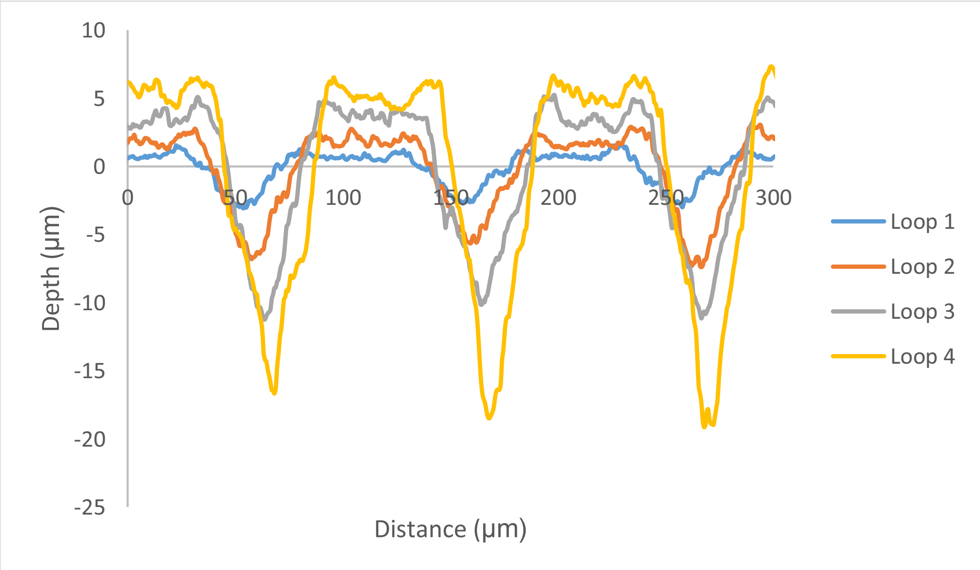

Fig. 2. Surface profiles under different laser loop of textured copper substrate.

Based on Fig. ***1***(c) and the surface profiles, it is shown that the average depth for laser of the micro-groove is higher compared to loop 1 and 2 where it is in the range of 10-12 μm. This value begins to show that the depth of the micro-groove keep increasing when the laser loop increased.

Fig. ***1***(d) and Fig display the 2D images and surface profile of the laser loop 4 micro-groove on the copper substrate respectively. Based on the graph of the surface profile, the average depth of the micro-groove is 17-19 μm which makes the laser loop 4 has the deepest depth among all the laser loop that has been discussed before. This is due to the copper substrate of laser loop 4 has the longest time to absorb the laser energy which means that more material can be ablated. Thus, it can be concluded that the depth of the micro-groove of the copper substrate depends on the laser loop parameter.

3.2 Analysis of wettability of solder joint

Wettability is an important property in a soldering system for electronics as the reliable joint of the solder depends on the wetting angle. In this study, the wettability is quantitatively measured via the contact angle measurement. Solder wettability is determined from contact angle (°) to the copper (Cu) substrate where the better wettability of the solder interconnection comes from a smaller contact angle [21]. Based on Fig. ***2***, the highest measured contact angle is 17.84° for the non-textured copper substrate while the lowest contact angle is 10.4° for the micro-groove laser loop 4. The figure also revealed that the increasing laser loop parameter which increased the depth of micro-grooves are able to reduce the degree of contact angle. When the solder alloy (Sn-0.7Cu) is reflowed on the textured substrate, the solder alloy flows into the valleys of the micro-grooves by capillary action. The micro-groove on the copper substrate increases the surface area which indirectly increase the surface tension between the solder alloy and the substrate itself. The higher surface tension will allow the solder alloy to flow more into the valley and decrease the contact angle of solder joint. It can be concluded that the good wettability of the solder joint can be achieved by using textured substrate.

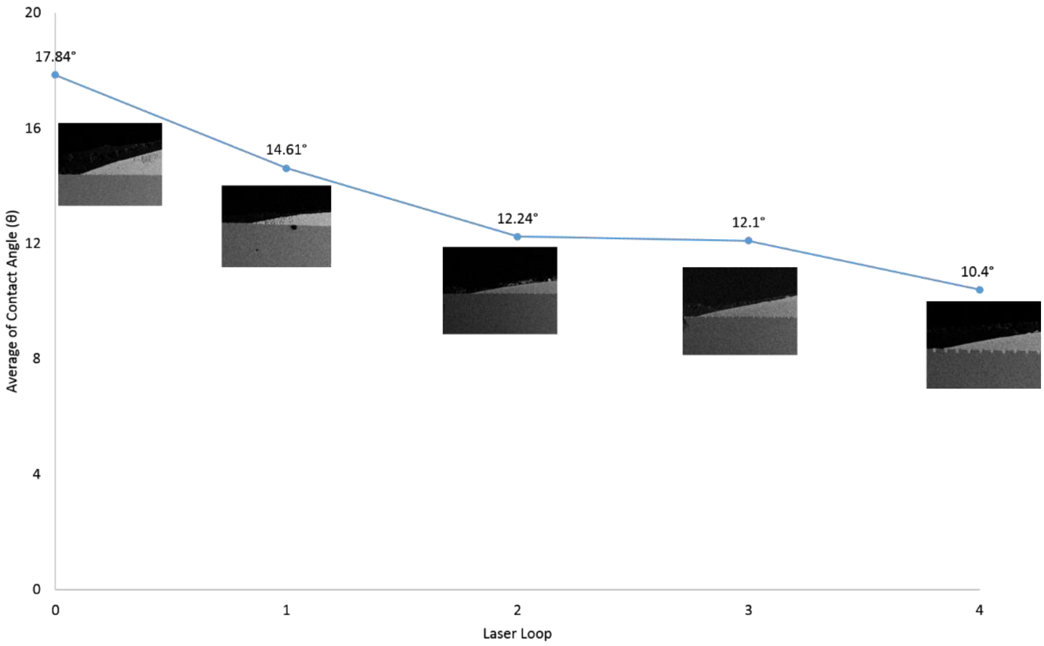

Fig. 3. Influence of micro-groove textured substrate on the contact angle in Sn-0.7Cu lead-free solder.

4 Conclusion

The effect of laser loop on surface morphology of copper substrate and wettability of solder joint have been investigated. The conclusion that can be made from this study are the microstructural observations from the surface profiles revealed that the increment in laser loop parameter affect the depth of the micro-groove formed on the copper substrates. The wetting properties decrease with the increasing depth of the micro-groove pattern and lowest contact angle of 10.4° was observed with laser loop 4 of micro-groove textured substrate.

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