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Lithography-Based Surface Modification of Copper for Soldering Application

N.A.H.M. Mahayuddin[a], J.A. Wahab[a,*],
M.A.M. Salleh[a], M.F.M. Nazeri[a], P. Postawa[b],
M. Nabiałek[c], B. Jeż[b] and J. Garus[d]

[a] *Centre of Excellent Geopolymer and Green Technology (CeGeoGTech),*
Universiti Malaysia Perlis (UniMAP), Kompleks Pusat Pengajian Jejawi 3,
Kawasan Perindustrian Jejawi, 02600, Arau, Perlis, Malaysia
[b] *Department of Technology and Automation, Faculty of Mechanical Engineering*
and Computer Science, Czestochowa University of Technology,
al. Armii Krajowej 19c, 42-200 Częstochowa, Poland
[c] *Department of Physics, Faculty of Production Engineering and Materials Technology,*
Czestochowa University of Technology, al. Armii Krajowej 19, 42-200 Częstochowa, Poland
[d] *Department of Mechanics and Fundamentals of Machinery Design,*
Faculty of Mechanical Engineering and Computer Science,
Częstochowa University of Technology, Dąbrowskiego 73, 42-201 Częstochowa, Poland

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*e-mail: juyana@unimap.edu.my

This paper details the fabrication of dimple micro-texture on a copper substrate surface using the photolithography technique and the effect of dimple micro-textured surface on soldering. Dimple micro-textures with diameters of 100–500 μm were fabricated on a copper substrate. Then, the Sn–0.7Cu solder was reflowed onto the textured copper substrate. The solderability and wettability of Sn-0.7Cu solder were investigated using optical microscopy, the 3D surface profiler, and visual tests. The results showed that that the Sn-0.7Cu reflowed on textured substrate has a smaller spreading area than its non-textured counterpart. The dimple micro-texture resulted in a smaller spreading area and lower contact angles, indicating improved solderability.

topics: dimple micro-texture, photolithography, lead-free solder, wettability

1. Introduction

Surface texture technology is ubiquitous in engineering due to advances in precision manufacturing technology. Textured surfaces are also present in nature, seen in lotus leaves, frog toes, and shark skin, all of which have been thoroughly studied to elucidate their respective characteristics [1, 2], with positive outcomes on properties such as superhydrophobicity, friction via adhesion, and drag reduction [3].

Recently, various techniques of surface texturing have been developed, such as diamond cutting, laser surface machining, lithography, electrochemical machining, ion beam etching, and micromilling [4, 5]. The lithography texturing technology uses light for patterning to balance the quality and complexity of the final specified texture at a low processing temperature compared to laser surface texturing. It is widely used in nano-processing due to its unique advantages, such as the better resolution of feature size, processing reliability, accuracy of alignment, and flexibility in pattern replication [6]. Photolithography produces various textured patterns on the substrates' surfaces using UV light. Surface-modified substrates with microtextures, such as dimples formed via photolithography, are promising prospects for electronic packaging applications to enhance the wettability and solderability of lead-free solders.

It is believed that the surface roughness of the micro-textured copper substrate affects the fluidity behaviors of the molten solder [7]. However, the effect of dimple micro-texture formation and etching time on the wettability of lead-free solders such as Sn–0.7Cu is yet to be systematically reported. Therefore, in this study, the fabrication process of the micro-textured copper substrate using the photolithography technique will be investigated, and its effect on the wettability of lead-free solder will be analyzed to expand its potential application in electronic packaging.

2. Methodology

2.1. Fabrication of dimple micro-texture

A high purity copper plate (99.9%) measuring $15 \times 15 \times 1$ mm^3 was selected as the substrate material in this work alongside the Sn–0.7Cu solder alloy. The dimple micro-textures were fabricated using the photolithography method. Dimples with diameters of 100–500 μm were fabricated, with the distance between the dimples of 300 μm. The samples are named according to the dimple diameter, i.e., $\mathrm{T}_{D100\mu\mathrm{m}}$, $\mathrm{T}_{D200\mu\mathrm{m}}$, $\mathrm{T}_{D300\mu\mathrm{m}}$, $\mathrm{T}_{D400\mu\mathrm{m}}$, and $\mathrm{T}_{D500\mu\mathrm{m}}$. Figure 1 shows the schematic diagram of the dimple micro-textured copper substrate. In the fabrication process, a positive photoresist was applied onto the copper substrate using the spin coater at a rotating speed of 850 rpm for 15 s at the beginning, then increased up to 3000 rpm for 30 s. The spin coater was finally stopped for 15 s, followed by a soft baking at 90°C for 90 s. Then the coated sample was exposed to UV light using the photolithography mask aligner for 120 s. An RD-6 developer was used to remove unwanted parts of the photoresist coating on the substrates' surface. Ferric chloride was used as an etchant for the copper substrate. The etching time was from 15 to 45 s and the hard bake process was carried out at 90°C for 60 s. The dimples depth was measured using a 3D profiler.

2.2. Soldering process

The Sn–0.7Cu solder alloy was fabricated using the casting method. Then, the 0.4 g Sn–0.7Cu solder ball was soldered onto the copper substrate with a small amount of resin mildly activated (RMA) flux in a reflow oven. In this study, the non-textured sample functioned as a control. The spreading area of the solder on all samples was observed via visual tests and measured using the ImageJ analyzer. The sample was cross-sectioned, and the contact angles between the Sn–0.7Cu solder with the substrate were determined using an optical microscope and Image-J analyzer. In this study, samples of $\mathrm{T}_{D300\mu\mathrm{m}}$ and $\mathrm{T}_{D500\mu\mathrm{m}}$ were selected for the soldering process.

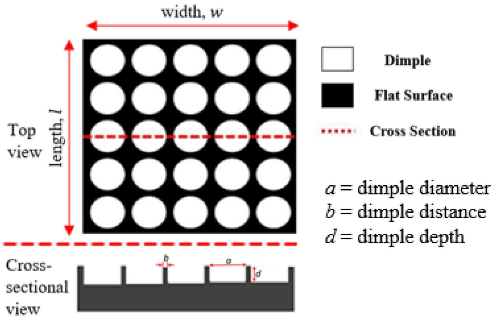

Fig. 1. Schematic diagram of dimple micro-textured copper with cross-sectional view.

3. Results and discussions

3.1. Fabrication of dimple micro-texture

It was shown that as the etching time increased, the depth of dimple micro-textured for all samples increased. The sample $\mathrm{T}_{D500\mu\mathrm{m}}$ showed the maximum depth, which was around 29.17 $\pm$ 0.5 μm. The formation of dimple micro-texture on the surface of the substrate is believed to improve the wettability of lead-free solder. Figure 2 shows a 3D image of a dimple for a sample of $\mathrm{T}_{D500\mu\mathrm{m}}$ etched for 45 s.

3.2. Spreading and wetting of Sn–0.7Cu solder

The spreading areas of the solidified solder were measured and compared between the non-textured and textured substrate. It was shown that the spreading area of the solder decreased as the dimple micro-textures were introduced onto the copper substrate. Both samples of $\mathrm{T}_{D300\mu\mathrm{m}}$ and $\mathrm{T}_{D500\mu\mathrm{m}}$ have smaller spreading areas, which were about 61.017 mm^2 and 66.031 mm^2, respectively. The molten solder required a more significant driving force to flow over the textured sample at a fixed time

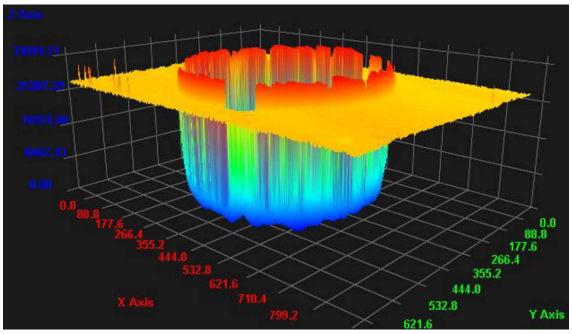

Fig. 2. 3D image of dimple for $\mathrm{T}_{D500\mu\mathrm{m}}$ etched for 45 s.

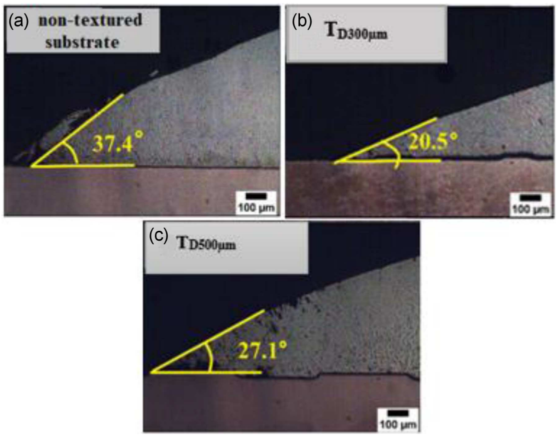

Fig. 3. Contact angle of Sn–0.7Cu solder (a) non-textured substrate, (b) $T_{D300\mu\mathrm{m}}$ and (c) $T_{D500\mu\mathrm{m}}$.

to spread. This was due to the presence of micro-texture on the surface that hindered the spreading of solder. The molten solder flowing and trapped into the dimple indicates a Wenzel state and also results in a small spreading area. On the other hand, for the non-textured substrate, the spreading area of the solder was about 84.56 mm^2. The smooth surface facilitated the spreading of the molten solder to a wide area. These results were found to be in agreement with Satyanarayan et al. [8] research, where they reported that surface roughness is a crucial factor that affects the wetting of fluids and molten solders, and that the rough surface has more interfacial area available for spreading the liquid.

Figure 3 shows the solder's contact angle (θ [°]) for all non-textured and textured samples. The contact angle of solder on the micro-textured copper substrate is lower relative to that of the non-textured copper surface, indicating that the contact angle has improved with the presence of the dimple micro-texture on the copper substrate. The contact angle for $\mathrm{T}_{D300\mu\mathrm{m}}$ was reported to be the lowest, at $\theta = 20.5°$, followed by $\mathrm{T}_{D500\mu\mathrm{m}}$ at $\theta = 27.1°$, and the non-textured surface at $\theta = 37.4°$. The existence of dimple micro-texture on the substrate surface entrapped the molten solder inside the dimple (cavity) and thus, led to the lower contact angle. This penetration of the solder into the dimple obeyed the Wenzel model [9]. High dimple density on the substrate surface was attributed to the increment in surface roughness, which resulted in a lower contact angle. A similar result was revealed by Kubiak et al. [10] and Wang et al. [11], who studied the wettability versus roughness of the surface. They have reported that wetting properties can be improved by small changes in surface roughness.

4. Conclusions

This paper detailed the investigation into the fabrication of the dimple micro-texture on a textured copper substrate using the photolithography technique. Introducing the dimple micro-texture on the copper substrate requires a fully developed condition during the development steps, and as the dimples' diameter increases, its depth increases at a similar etching time. Both the $\mathrm{T}_{D300\mu\mathrm{m}}$ and $\mathrm{T}_{D500\mu\mathrm{m}}$ samples were reported to have smaller spreading areas and lower contact angles compared to the non-textured copper substrate. Overall, the dimple micro-texture fabricated on a copper substrate can improve the solderability of Sn–0.7Cu Pb-free solder and thus has a great potential, particularly in interconnect applications.

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