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RESEARCH ARTICLE

Laser surface roughening on copper analyzed using SEM-EDX

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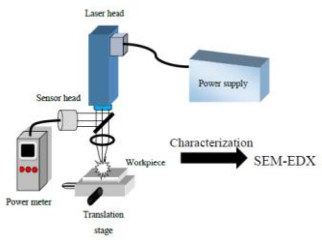
Graphical abstract



Abstract

Microstructure, and chemical composition changes on the copper surface were investigated using SEM-EDX analysis. A Q-switched Nd:YAG laser was focused at laser energy of 224 mJ and 465 mJ to rough the copper surface. Higher laser energy were responsible for increasing laser surface roughening process. The rapid heat and cooling process introduced a non-equilibrium condition causing changes in the microstructure as well as the chemical composition of the rough copper surface. The heavier the roughening effect will affect, the larger the advantage of adhesive bonding between copper surfaces will be.

Keywords: *chemical composition; laser surface roughening; microstructure.*

INTRODUCTION

Laser surface roughening (LSR) is constituted of a laser beam machining (LBM) which is a part of laser material processing. LSR is a thermal process (Webb, 1986). The effectiveness of this process depends on thermal properties and, to a certain extent, the optical properties rather than the mechanical properties of the material to be machined. Therefore, materials that exhibit a high degree of brittleness, or hardness, and have favorable thermal properties, such as low thermal diffusivity and conductivity, are particularly well suited for laser machining (Bertolotti, 1983). Thus copper is particularly suitable for laser beam machining.

Copper by nature has a high affinity to oxygen and is readily oxidized when exposed to elevated temperatures. The degree of oxidation will in general be a function of temperature, environmental conditions, heating duration, surface impurities or contaminants and surface finish of the metal (Kofstad. P, 1990). Low cost, high thermal and electric conductivity, easy fabrication and joining, and wide range of attainable mechanical properties have made copper as one of main materials for lead frames, interconnection wires, foils for flexible circuits, heat sinks, and traces in PWB in electronic packaging (Zheng, 2003).

Nd:YAG laser is the most widely used application for LSR. This is because the characteristics of unique and useful laser in material processing (Norikazu. T, et al., 1996). Nd:YAG laser also has a low power beam but when operated in pulsed mode high peak power enables the machine more concentrated materials. Also, the short pulses suitable for machining thin materials. Due to the shorter wavelength (1 µm) it can be absorbed by materials of high reflective difficult to machine with CO_2 laser (Meijer, 2004).

Surface morphology is a parameter effectively represents the roughening surface quality by laser. (Dubey et al., 2007). According to Ghany et al., 2005, who reported that reduce the surface morphology to increase the cutting speed and frequency, and reduce the laser power and gas pressure. Also nitrogen gives a better surface finish than oxygen. In another study (Chen, 1999) also shows the available surface morphology reduced at increasing pressure in the case of nitrogen and argon but give the surface a bad air outside the 6 bar pressure. Also, the surface morphology better at higher speeds. While the study by Rajaram et al., (2003) showed that the laser power and cutting speed has a major effects on surface morphology and striation (periodic stripes on the surface of the piece) frequency. They have shown that the optimum feed rate, surface morphology is minimal laser power and has little effect the surface morphology but does not affect the frequency of striation.

However, systematic investigation of the surface morphology and the change in chemical composition has received little attention. Hence, in the present paper we intend to demonstrate the effect of the laser energy on the microstructure and chemical composition of the copper surface before and after laser treatment.

EXPERIMENTAL

Materials

A plate of pure copper with having a smooth surface was employed as a specimen. The thickness of the copper plate is 2 mm. Copper plate is usually used as a lead-frame chip integrated. The copper plate was cut into pieces with dimensions of length and width of 2 x 2 cm^2. Copper surface subsequently treated with laser energy of 224 mJ and 465 mJ to rough the surface.

Method of Laser Surface Roughening

A Q-switched Nd:YAG laser with a wavelength of 1064 nm basis, operating at a frequency of 1 Hz, was used as an energy source. Laser was focused on the convex lens that has a focal length of 100 mm. In order to enlarge the area of the laser spot, the target is located on the defocused distance of about 300 mm from the focal point to form the rough surfaces.

Characterization of copper surfaces

Copper sample microstructure is characterized by using optical scanning electron microscope (SEM). Changes in the chemical composition of the copper surfaces analyzed using energy dispersive x-ray spectroscopy (EDX).

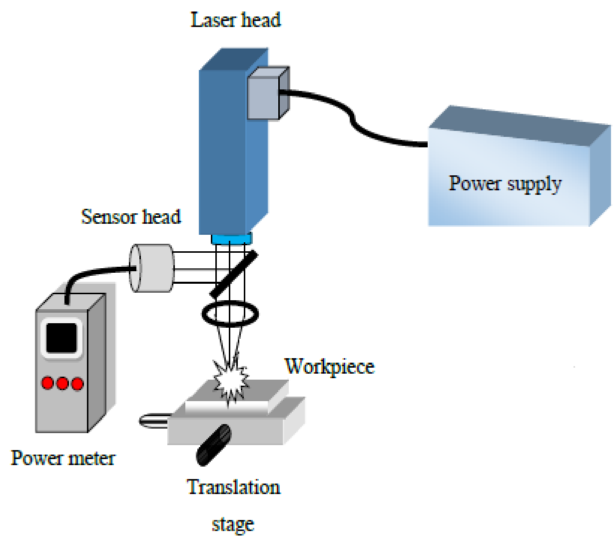


Fig. 1 Laser surface roughening system.

RESULTS AND DISCUSSION

Surface morphology before laser treatment

The microstructure of pure copper before treatment with laser energy was examined by SEM, as shown in Fig 2. The composition Cu, C and O are expected to be observed as individual particles in pure copper and the spectrum of the chemical composition of pure copper material shown in Fig 2 and weight percentage detail for each element analyzed by EDX spectroscopy are listed in Table 1.

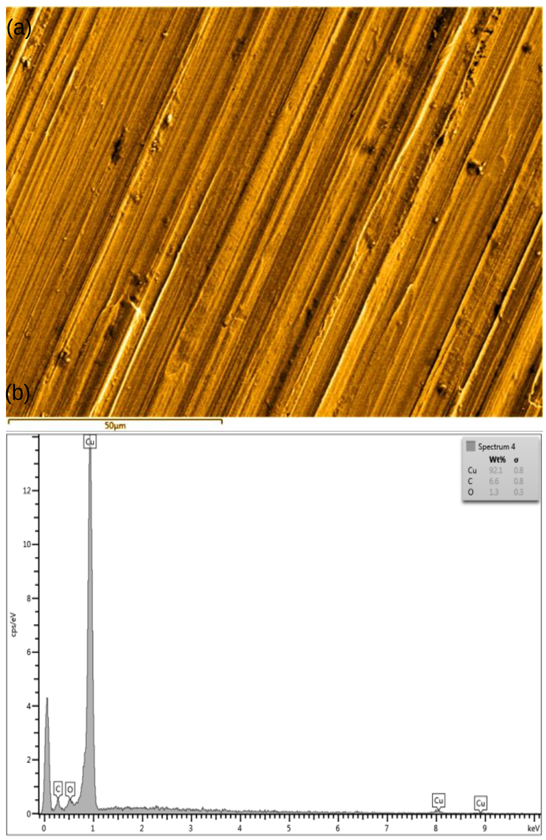


Fig. 2 (a) Microstructure of sample before laser treatment (b) Spectrum of EDX analysis before laser treatment.

Table 1: EDX analysis of the copper before laser treatment.

Element	Weight %
Copper (Cu)	92.1
Carbon (C)	6.6
Oxygen (O)	1.3

Laser Surface Roughening based on different energy

SEM images of copper surfaces after treatment with different energy are shown in Fig.3. A top-view micrograph of the roughening surface with a higher magnification at 10µm shows at Fig.3(a). The surface rippling which considered as the distinguishing topological feature of the laser-melted region. This also reveal that the roughening surface contains porosity (as shown by arrow). The surface ripples originate in fluid flow in the melt pool due to surface tension gradients, convection and pressure effects. It is noticed that, laser induced breakdown produces high-pressure shock waves on the treated surface. The effects of such high pressure are particularly important in transporting liquid during the duration of the applied pulse. As a result, the surface ripples are formed which are thus frozen in upon rapid solidification of the melt pool and reveal the laser surface roughening regions contain porosity. Porosity is the formation of bubbles within the roughening after it has cooled. The size of porosity is variation about 1-10 nm.

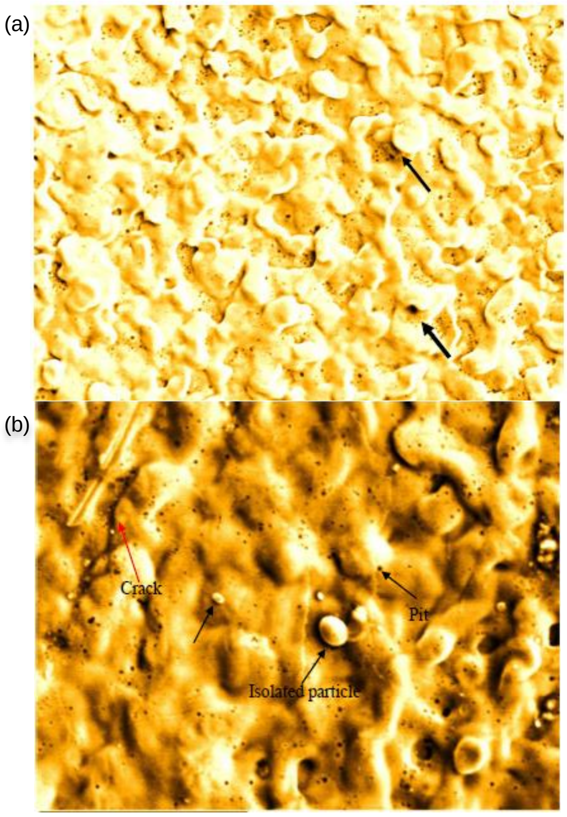


Fig. 3 SEM images of copper surfaces after treatment at laser energy (a)224 mJ and (b) 465mJ.

Fig. 3(b) show the surface morphology in this case was more homogeneous and porosities free is successfully produced in comparison to roughening surface with laser energy 224 mJ. In additional there is a small crack as shown by a red arrow and many pits distributed all over surface layer. Solidification growth with different sizes can be clearly seen in this region. Such solidified regions were created due to rapid solidification involved in the laser treatment. The rapidness depends on the duration or the lifetime of the pulse existed during interaction. In this work, the pulse duration is 10 ns, meaning that is the period taken for the heat conduction as well as for quenching. But amazing within such ultra-short time the melting and resolidified can take over at once. The energetic of the focused laser with microbreakdown is actually providing peak power of 46.5 MW within 10 ns time. Furthermore the breakdown is associated with plasma formation which has temperature more than 11000°C and high pressure from shock wave. The condition carried out by the Nd:YAG laser is much higher than the melting point of copper (1085°C). Therefore the energetic power delivered by the laser smashing the copper surface and induced roughening, The energetic impact from high pressure also result in crack on the surface and the formation isolated particle.

Table 2 EDX analysis of the copper after laser treatment at different energy.

Element	Weight%	
	(a) 224 mJ	(b) 465 mJ
Copper(Cu)	92.1	93.5
Carbon(C)	5.6	3.5
Oxygen(O)	2.4	3.0

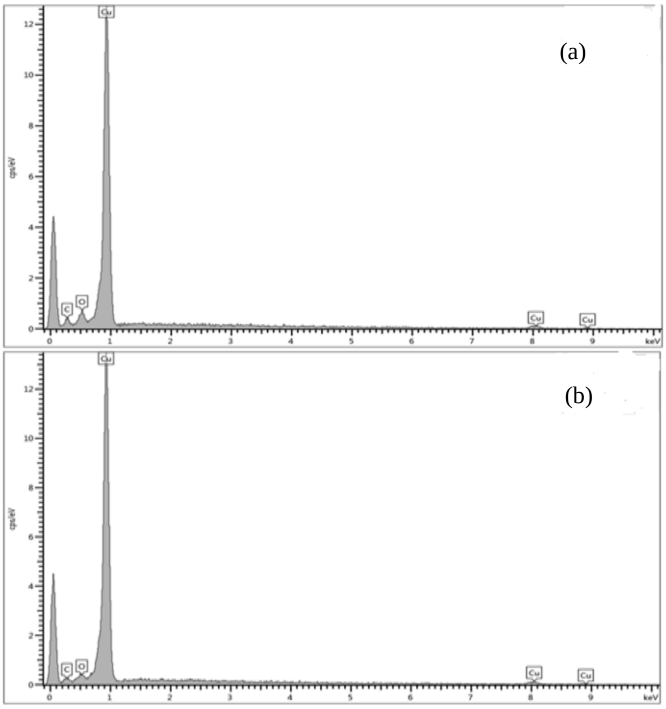


Fig. 3 Spectrum of chemical composition via EDX analysis at different energy (a) 224 mJ (b) 465mJ.

The composition Cu, C and O are expected to be observed as individual particles in pure copper. The chemical composition of pure copper material is shown in Figure 3. The detail of weight percentage for each element that has been analyzed by EDX spectroscopy is listed in Table 1. Table 1(a) shows that the percentage by weight of copper is 92.1 % followed by 5.6 % carbon and 2.4% oxygen. The oxygen has significantly increased due to the laser oxidation effect, since the experiment was carried out in open air. However the carbon percentage is reduced due to the laser ablation effect whereby the carbon element has been burnt and removed the particles from the surface. Chemical composition of pure copper material is shown in Figure 3 (b). Weight percentage detail for each element analyzed by EDX spectroscopy is listed in Table 1. Table 1(b) shows that the percentage by weight of copper is increased with 93.5 % followed by 3.5 % carbon and oxygen are present in 3.0% of pure copper. In comparison to the copper sample at laser energy 224 mJ as shown in Table 1(a), the oxygen has significantly increased about 0.6% due to the laser oxidation effect, since the experiment was carried out in open air. However the carbon percentage is reduced about 2.1% due to the laser ablation effect whereby the carbon element has been burnt and removed the particles from the surface.

CONCLUSION

The microstructure of roughening copper surface has been investigated using SEM-EDX analysis. The copper surface was rough using the laser technique at laser energy of 224 mJ and 465 mJ. The higher of the laser energy were responsible for increasing the roughening process. The SEM results show that the microstructure drastically changed with the laser energy. Most of the roughening surface a free from porosity and free from crack as increasing of laser energy. This will give advantages in adhesive bonding. Meanwhile, the EDX analysis show the oxygen has significantly increased due to the laser oxidation effect, However the carbon percentage is reduced due to the laser ablation effect whereby the carbon element has been burnt and removed the particles from the surface.

ACKNOWLEDGEMENT

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