CHARACTERIZATION OF LASER SURFACE ROUGHENING ON COPPER USING A Q-SWITCHED Nd:YAG LASER

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Physics)

Faculty of Science
Universiti Teknologi Malaysia

JANUARY 2019

DEDICATION

Untuk kemanusiaan....

Semoga lebih tunduk, taat dan bergantung harap kepada Penciptanya

ACKNOWLEDEGMENT

In the Name of Allah S.W.T, Most Gracious and Merciful

Alhamdulillah and thanks to Allah S.WT administrator of the worlds, whom we praise, ask for help and ask for forgiveness. We seek refuge with Allah S.W.T from the evil ourselves and cons of our practice. Peace and blessings be upon to Prophet Muhammad S.A.W who convey his message so as to remove these people from darkness with Allah S.W.T permission. Peace and blessings be upon the Prophet's family also, his companions and those who follow the Sunnah of the Prophet until the Day of Resurrection.

First and foremost, I would like to thank Universiti Teknologi Malaysia for giving me the chance to further my academic development to another level. My utmost gratitude goes to my supervisors Prof. Dr. Noriah Bidin and Assosiate Prof. Dr. Hazri Bin Bakhtiar for the continuous encouragement as i hurdle all obstacles in completing this research. Without the knowledge and assistance this study would not have been successful. Deepest gratitude also to Laser Centre, Ibnu Sina Institute for Scientific and Industrial Research, UTM and Physics Department, Faculty of Science UTM for the equipment, facilities and also great support from the staffs.

My thanks also to Education Sponsorship Division, Ministry of Education Malaysia for the financial support on research study. Finally, I am forever indebted to my parents, my beloved wife, sons and all other members of the family for their understanding, endless patience and encouragement when it was most required

ABSTRACT

Laser surface roughening (LSR) is a new surface treatment. Copper is a good conductor and it is the key material to a lead frame in electronic packaging that serves mainly to support chip. However, LSR is still at an infant stage compared to chemical methods that are widely used to roughen the copper surface in modern material processing. The problem with chemical methods is that it cannot be controlled and involves waste or pollution which is not environmental friendly and requires high budget. Therefore, in attempt to shed light on this matter, a fundamental study is carried out by roughening copper surface using laser at different parameters including energies and number of pulses. LSR system is developed using a Q-switched Nd:YAG laser with fundamental wavelength of 1064 nm and pulse duration of 10 ns. In this process, the laser energies used in the range from 150 mJ until 600 mJ. An adhesion test was carried out on copper plates to study the relationship between the surface roughness and the adhesion force. A plate of a pure copper with a smooth surface was employed as a sample. When the Q-switched Nd:YAG laser is focused on the sample, the roughening copper surface formed and was analyzed using atomic force microscope (afm), field emission scanning electron microscope and high resolution x-ray diffractometer. Average roughness and root mean square roughness increase with laser energies and number of pulses. Therefore, the surface roughness processing is strongly dependent on the laser energies and number of pulses. The stronger the laser energies and number of pulses, the higher is the roughness of the copper surface. The scanning electron microscope results show that the microstructure drastically changed with the laser energies and number of pulses. Most of the surface roughness is free from porosity and crack even at increasing laser energies and number of pulses. This will give advantages in adhesive bonding. The adhesion test shows that when the surface roughness increases, the adhesion force also increases. These conditions may also give an advantage to the surface roughness with increasing the Q-switched Nd:YAG laser will provide a strong bond to the surface in order to improve the adhesion force. Therefore, LSR process can be a beneficial method for roughening the copper surface compared to existing methods.

ABSTRAK

Kekasaran permukaan dengan laser (LSR) adalah rawatan permukaan baru. Kuprum adalah konduktor yang baik dan ia adalah bahan utama kepada kerangka utama dalam pemasangan elektronik yang berfungsi terutamanya untuk menyokong cip.Walau bagaimana pun, LSR masih di peringkat awal berbanding dengan kaedah kimia yang digunakan secara meluas untuk kasar permukaan kuprum dalam pemprosesan bahan moden. Masalah dengan kaedah kimia ia tidak boleh dikawal, melibatkan pembaziran atau pencemaran kepada alam sekitar dan memerlukan belanjawan yang tinggi. Oleh itu, dalam usaha untuk memberi penerangan tentang perkara ini, satu kajian asas kekasaran permukaan kuprum menggunakan laser pada parameter seperti tenaga dan bilangan denyutan yang berbeza dijalankan. Sistem LSR dibangunkan menggunakan laser Nd:YAG bersuis-Q dengan panjang gelombang asas 1064nm dan tempoh denyutan 10 ns. Dalam proses ini, tenaga laser yang digunakan dalam julat daripada 150 mJ hingga 600 mJ. Ujian lekatan dijalankan ke atas plat kuprum untuk mengkaji hubungan antara kekasaran permukaan kuprum dengan daya lekatan. Plat kuprum tulen dengan permukaan licin telah digunakan sebagai sampel. Apabila laser Nd:YAG bersuis-Q difokuskan kepada sampel, kekasaran permukaan terbentuk pada kuprum, seterusnya dianalisis menggunakan mikroskop daya atom, mikroskop elektron pengimbasan pelepasan medan dan diffractometer x-ray resolusi tinggi. Kekasaran purata dan kekasaran punca min persegi meningkat dengan tenaga dan bilangan denyutan laser yang meningkat. Semakin kuat tenaga laser dan bilangan denyutan laser semakin tinggi kekasaran permukaan kuprum. Keputusan mikroskop elektron pengimbasan menunjukkan bahawa mikrostruktur berubah secara drastik dengan peningkatan tenaga dan bilangan denyut laser. Kebanyakan kekasaran permukaan bebas daripada keliangan dan bebas daripada retak walau pun pada peningkatan tenaga dan bilangan denyutan laser. Ini akan memberikan kelebihan dalam ikatan pelekat. Ujian lekatan menunjukkan bahawa apabila peningkatan kekasaran permukaan, daya lekatan juga meningkat. Keadaan ini juga boleh memberi kelebihan kepada kekasaran permukaan dengan peningkatan laser Nd:YAG bersuis-Q akan menyediakan ikatan yang kuat ke permukaan untuk meningkatkan daya lekatan. Oleh itu, proses LSR boleh menjadi kaedah bermanfaat untuk kekasaran permukaan kuprum berbanding kaedah sedia ada.

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LIST OF ABBREVIATIONS

LSR	-	Laser surface roughening
LBM	-	Laser beam machining
CO_2 laser	-	Carbon dioxide
Nd:YAG	-	Neodymium doped yttrium aluminium garnet \
AFM	-	Atomic force microscope
SEM	-	Scanning electron microscope
EDX	-	Energy- dispersive x-ray
FESEM	-	Field emission scanning electron microscope
XRD	-	High Resolution X-ray Diffractometer
R_a	-	Average Roughness
R_q rms	-	Root Mean Square Roughness
R_{sk}	-	Surface Skewness Roughness
R_{ku}	-	Surface Kurtosis Roughness
Cu	-	Copper
C	-	Carbon
O	-	Oxygen

LIST OF SYMBOLS

E	-	Laser energy
I	-	Intensity
P_0	-	Laser power
α	-	Material absorbtion coefficient
d	-	Penetration depth
κ	-	Thermal conductivity
ρ	-	Material density
c	-	Specific heat capacity
Z_R	-	Rayleigh length
Ω	-	Beam waist
t	-	Time
F	-	Focal length
k_B	-	Boltzmann's constant
T	-	Temperature
Γ	-	Liquid viscosity

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CHAPTER 1

INTRODUCTION

1.1 Overview

Laser surface roughening (LSR) is constituted of a laser beam machining (LBM). LBM is a piece of laser materials processing. Laser materials processing comprises of a huge group of procedures for material expelling, or machining, warm treating, nearby surface changes, and so forth. LBM can supplant mechanical evacuation techniques in numerous modern applications, especially in the preparing of hard to-machine materials, for example, solidified metals, earthenware production, and composites.

LSR is a thermal process (Webb, 1986). The effectiveness of this process relies upon thermal properties and, to a specific degree, the optical properties as opposed to the mechanical properties of the material to be machined. Subsequently, materials that show a high level of weakness, or hardness, and have ideal warm properties, for example, low thermal diffusivity and conductivity, are especially appropriate for laser Beam machining (Bertolotti, 1983).

LSR is a non-contact process. Since energy exchange between the laser and the material happens through light, no cutting strengths are produced by the laser, prompting the nonappearance of mechanically incited material harm, apparatus wear, and machine vibration. Also, the material evacuation rate for laser machining is not restricted by requirements, for example, most extreme instrument constrain, developed edge arrangement, or device gab. Laser beam machining is an adaptable procedure. At the point when joined with a multi-pivot work piece situating framework or robot, the laser shaft can be utilized for boring, cutting, scoring, welding, and warmth treating forms on a solitary machine. This adaptability disposes of transportation essential for preparing parts with an arrangement of particular machines. Likewise, laser beam machining can bring about higher exactness and littler kerf widths or gap distances across than delivered by equivalent mechanical procedures (Chryssolouris,1991).

Copper by nature has a high liking to oxygen and is promptly oxidized when presented to lifted temperatures. The level of oxidation will when all is said in done be a component of temperature, natural conditions, warming span, surface polluting influences or contaminants and surface complete of the metal (Per Kofstad, 1990). Ease, high warm and electric conductivity, simple manufacturing and joining, and extensive variety of achievable mechanical properties have made copper as one of principle materials for lead frames, interconnection wires, foils for adaptable circuits, warm sinks, and follows in PWB in electronic packaging.(Zheng Y., 2003)

In any case, not at all like aluminum oxide, the copper oxide layer is not self-ensure so the copper is promptly oxidized. Copper oxidation is considered as a genuine dependability issue in microelectronic bundle. It produces cracks at Cu-Al interface on the copper interconnection wire, causes delamination between the copper lead frames die pad and molding compound, and prompts poor adhesion between the copper lead frames and molding compound (Zheng Y., 2003). Yoshioka et al.1989 announced poor adhesion to copper oxide aggravate that shape has caused disintegration issues caused by entrance of dampness through the arrangement of breaks. Kim et al., 1991 likewise announced poor adhesion between copper oxide and mold compound and adhesion properties of the surface copper oxide considered. Ohsuga et al, 2000, have revealed the reliance of the adhesion strength of copper and their oxidation organize. According to some researchers Kazuyoshi kushike *et., al* (1976), Novel J Nelson *et..al* (1986), Chris C. Yu *et..al* (1993), Hidaeki H. *et..al*

(2002) and Yar Ein E. *et..al* (2011) claim that the surface roughness of integrated chips have been carried out using chemical methods. The technique used to deal with the delimitation surface is achieved by roughening the surface of the copper. But there is a problem with this chemical methods because their use can not be controlled, involving waste or pollution drive un environmentally friendly and requires a high budget

Typically Nd : YAG and CO_2 laser is the most widely used application for LSR. This is because the characteristics of unique and useful laser in material processing. CO_2 laser has a wavelength of 10 µm infrared region. It has an average power, better efficiency and good beam quality. It is suitable for fine hair cutting sheet metal at high speed (Norikazu. T, *et al.*, 1996). While the Nd:YAG laser 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).

LSR being a thermal process incites numerous unfavorable impacts in workpiece material which thus influences the mechanical properties too. The greater part of the execution attributes talked about by different researchers identify with geometrical, metallurgical and surface qualities, for example, surface roughness, taper formation and heat affected zones. Exhaustion quality, small scale hardness, and lingering stresses are likewise imperative execution measures which are required to be improved. In this way, change of mechanical properties during LSR is a research range of interest (Meijer, 2004).

Surface roughness is a parameter effectively represents the roughening surface quality by laser. (Dubey *et al.*, 2007). As indicated by Ghany et al., 2005, who detailed that decrease the surface roughness to build the cutting rate and recurrence, and lessen the laser power and gas weight. Additionally nitrogen gives a superior surface complete than oxygen. In another investigation (Chen, 1999) likewise demonstrates the accessible surface roughness diminished at expanding weight on account of nitrogen and argon however give the surface a terrible air outside the 6 bar weight. Additionally, the surface roughness better at higher rates.

While the study by Rajaram et al., (2003) demonstrated that the laser power and cutting pace has a noteworthy consequences for surface roughness and striation (intermittent stripes on the surface of the piece) recurrence. They have demonstrated that the ideal encourage rate, surface roughness is negligible laser control and has little impact the surface roughness however does not influence the recurrence of striation. Al-Sulaiman, F.A., *et al* (2006) also state that surface roughness of cu multi laminated reduce as the less power of intensity laser while Li, L., *et al* (2007) state that by using LSR method, the surface roughness of cu sheet increase as a maximum power laser drilling also increase. Khalfallah, I.Y.*et al* (2010) state that by using LSR method, the increase surface roughness of cu sheet without affecting the bulk properties by increasing the laser power. Donald, C. A. (2012) by using LSR method surface roughness of cu sheet increase by increasing laser energy/power without affecting the bulk. Jabbareh, M. A., *et al.* (2013) Surface roughness increase as a max power Q-switched laser drilling as number of pulses also increase. Wang, Q., *et al.,* (2015) by using femtosecond Nd:Yag laser as LSR method, the surface morphology/roughness of cu increase while the hole evolution during drilling also increase. To that, copper is particularly suitable for LSR. Overall, this study will focus on the fundamental aspects of LSR especially surface roughness that will reflect the quality of the machined surface by laser. As a result of the quality of surface roughness will be correlated with the adhesion on copper surfaces are considered suitable as IC lead frames.

1.2 Problem Statement

Today in modern industrial applications, the material that has a low cost, high thermal conductivity and electrical, easily fabrication lead to high demand, especially in the electronic packaging industry. Copper is one of the materials that has a variety of mechanical characteristics adopted as one of the key ingredients to a lead frame in electronic packaging that serves mainly to support chip but still there are problems because copper oxidation in the area of the copper leadframe die pad and molding compound causes the delamination of packages and induces poor adhesion in the area of copper lead frame and molding compound, so that the dampness can infiltrate through the crevices making consumption issue in packages. LSR is the most reasonable and generally utilized process to machine copper. The vast majority of the execution attributes examined by different researchers identify with geometrical, metallurgical and surface qualities, for example, surface roughness, taper formation and Heat affected zones. Surface roughness is vital execution measure which required to be made strides. Along these lines, improve the surface roughness properties utilizing LSR is a research area of interest. Delimination of the area of the copper lead frame and molding compound either due to temperature or moisture will cause contact failure. This is among the big issue in semiconductor industry. Thus various techniques are employed to address the problem. Commonly this problem is accomplished by roughening the surface. Currently the most surface roughness of the area of the copper lead frame have been carried out using chemical methods. The problem with the chemical method is where the oxide is formed on the copper surface. The oxide process has many weaknesses. The oxide process is also known where an oxide having a rough surface is formed on the copper surface. The normal oxide process is carried out at such high temperatures so that the substrate is often distorted, causing quality control problems and additional production costs. The oxidation process is also associated with the problem of uniformity in which the copper surface is oxidised or coated by oxidation solution. The non-economic method drive reseacher to explore new technique. In this work, laser was used to roughening the surface of copper plate.

1.3 Research Objectives

The main objective of the whole research is to characterize the Laser Surface Roughening (LSR) on copper. In attempt to achieve this goal various studies will be carried out including:

1. To characterize the laser surface roughening on copper at different parameters including energy and number of pulses.
2. To analyze the surface roughness on copper via AFM, SEM, EDX, XRD and Mapping.
3. To determine the adhesion force of treated copper.

1.4 Research Significance

The economy, simplicity and fast technique to roughening the surface will give a big impact in semiconductor industrial application. Integrate chip is currently being used in most electronic device. The improvement of surface roughness on IC will solve the delamination problem. Such improvement will lead the IC utilization last long and better performance.

1.5 Research Scope

This study covers a specific area with just distinguished by the type of laser used, the techniques involved, and the materials under study and the instruments used for sample characterization. A Q-switched Nd: YAG laser operating at a fundamental wavelength of 1064 nm will be used as an energy source to drive the surface roughness formation on copper with different energy, frequency and number of pulses. Experiments will be conducted in the air to simulate the real field application of LSR. A pure copper plate with a smooth surface was used as a specimens with a thickness of 2 mm was cut in the size (length and width of 1 cm^2). Copper surface machined by the laser will be characterized by a several of techniques, namely atomic force microscope (AFM), scanning electron microscopy (SEM) coupled with energy dispersive spectroscopy, x-ray (EDX), field emission scanning electron microscope (FESEM) and X-Ray diffractometer system (XRD). An adhesion test carried out on copper plates to study the relationship between the surface roughness and the adhesion force using button shear method.

1.6 Thesis Outline

The whole research is archived in the thesis, and it comprises of five chapters. Every section is partitioned into each particular subchapter.

Chapter 1 depicts the overview of the thesis, problem statement, objectives and the scope of the research.

The complete theory of LSR process is explained in Chapter 2. Several major problems in LSR process are described briefly. It is followed by the literature review of different methods of implementation and techniques used as compared to our research in the several sub-chapters.

The experimental setups, and the techniques used in LSR process is covered in Chapter 3. The material used in the process is specified. Sample preparation for several characterization techniques used is also included.

All the results are presented and discussed in Chapter 4. The initial work comprised of laser system calibration, sample characterization and optimization and adhesive test.

At last, every one of the works are finished up in Chapter 5. This incorporates the outline of the outcomes accomplished from the experiment cooperates with a few suggestions for future investigation.

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