STRUCTURAL CHARACTERIZATION AND PROPERTIES OF LEAD-FREE SOLDERS ON DIFFERENT SURFACE ROUGHNESS OF COPPER SUBSTRATE

ONG CHIEN CHUNG
B051210075

UNIVERSITI TEKNIKAL MALAYSIA MELAKA
2016

UNIVERSITY TEKNIKAL MALAYSIA MELAKA

STRUCTURAL CHARACTERISATION AND PROPERTIES OF LEAD-FREE SOLDERS ON DIFFERENT SURFACE ROUGHNESS OF COPPER SUBSTRATE

This report is submitted in accordance with requirement of the University Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Engineering Materials) (Hons.).

by

ONG CHIEN CHUNG

B051210075

920924-07-5195

FACULTY OF MANUFACTURING ENGINEERING

2016

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

TAJUK: **Structural Characterization and Properties of Lead-Free Solders on different surface roughness of Copper Substrate.**

SESI PENGAJIAN: 2015/16 Semester 2

Saya **ONG CHIEN CHUNG**

mengaku membenarkan Laporan PSM ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Laporan PSM adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan laporan PSM ini sebagai bahan pertukaran antara institusi pengajian tinggi.

☐	SULIT	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysiasebagaimana yang termaktub dalam AKTA RAHSIA RASMI 1972)
☐	TERHAD	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)
☐	TIDAK TERHAD	

Disahkan oleh:

ONG CHIEN CHUNG

____

Alamat Tetap:

42-1075 TIARA VIEW,

JLN LOH POH HENG,

11200, TANJUNG BUNGAH, P.PINANG

Tarikh: 18th JUN 2016

Cop Rasmi:

Tarikh: _______________________

** Jika Laporan PSM ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan PSM ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I hereby, declared this report entitled "Structural Characterization and Properties of Lead-free solders on different surface roughness of Copper substrate" is the result of my own research except as cited in references.

Signature :

Author's Name : ONG CHIEN CHUNG

Date : 24 JUNE 2016

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Engineering Materials) (Hons.). The member of the supervisory committee is as follow:

……………………………………………

(PROFESOR DR. QUMRUL AHSAN)

ABSTRAK

Pateri tanpa plumbum (Pb) telah diperkenalkan untuk mengatasi masalah yang disebabkan oleh pateri yang berasaskan Pb. Kajian ini memberi tumpuan kepada kekuatan ikatan pateri tanpa Pb pada substrat tembaga (Cu) dengan kekasaran permukaan yang berbeza. Kekuatan ikatan bergantung kepada ikatan kimia daripada pembentukan sebatian antara logam (IMC) di antara pateri dan substrat. Bahan yang digunakan adalah pateri yang digunakan mengandungi 2 komposisi yang berbeza, iaitu 96.5Sn-3.0Ag-0.5Cu (SAC305) dan 95.5Sn-3.8Ag-0.7Cu (SAC387) dan substrat Cu dengan permukaan kasar dan halus. Objektif pertama adalah deposit pateri SAC305 dan SAC387 pada kekasaran permukaan yang berbeza. Analisis mikrostruktur pada gabungan pateri telah dilaku untuk memerhatikan kimia antara pateri dan substrat. Selepas pematerian aloi SAC pada substrat, sampel akan ditinggalkan dalam relau pada masa reaksi yang berbeza. Sampel kemudiannya diperhati dengan optikal mikroskop dan mikroskop imbasan elektron (SEM) untuk mengkaji morfologi di gabungan pateri. Seterusnya, sampel dikerat untuk mendapatkan nilai kekerasan dengan menggunakan pengujian mikro Vickers. Pencirian IMC melibatkan penggunaan teknik pembelauan sinar-X (XRD) untuk mendapatkan komposisi di gabungan pateri. Dengan kajian ini, didapati bahawa reaksi masa yang lebih lama akan menyebabkan lebih pembentukan IMC. Reaksi masa 3 jam pada suhu 125ºC menghasilkan sampel yang mempunyai kekerasan yang paling optimum. IMC Cu_6Sn_5, Cu_3Sn and Ag_3Sn telah dikesan dalam sampel. Akhirnya, permukaan kasar boleh menjadi lebih keras berbanding dengan permukaan halus pada masa reaksi yang lama.

ABSTRACT

The lead-free solders have been introduced to overcome the problem caused by the lead-based solders. This research will focus on the bond reliability of the lead-free solder on the copper (Cu) substrate with different surface roughness. The bond reliability strongly relies on the chemical bonding from the formation of the intermetallic compounds (IMC) between the solder and substrate. The materials used were solders wires with 2 different compositions, which were 96.5Sn-3.0Ag-0.5Cu (SAC305) and 95.5Sn-3.8Ag-0.7Cu (SAC387) and Cu substrates with coarse and fine surfaces prepared by grinding process. The primary objective is to deposit SAC305 and SAC387 on Cu substrates with different surface roughness. After soldering the SAC alloys on the substrates, the samples were left in the furnace at different ageing time. The samples were then put under the optical microscope and scanning electron microscope (SEM) to study the morphology. The hardness values were obtained from the solder joint using the micro Vickers hardness test. The IMC characterization was done using the X-ray diffractometer (XRD) to obtain the composition at the solder joint. From the result, the ageing duration has increased the IMC formation. Ageing for 3 hours at 125ºC give the most optimum hardness for both solders and surfaces. The Cu_6Sn_5, Cu_3Sn and Ag_3Sn IMC were found present in the samples. SAC387 showed more spheroid-shaped and long Cu_6Sn_5 IMC due to higher solder density. SAC387 was also harder than SAC305 due to the high Ag_3Sn content. Lastly, it has been founded that the coarse substrates can be harder than the fine surface with proper ageing duration for the solder to wet onto the surface of the substrate.

DEDICATION

First of all, I dedicated this thesis to my beloved mother,

***Ng Bee Hong**,*

who has been a constant source of support throughout the project. This work is also dedicated to my siblings and friends for their love and support. This include a previous friend of mine,

***Yap Sin Yin**,*

who has been giving me motivation and encouragement during difficulty. I am truly thankful for having you all in my life.

ACKNOWLEDGEMENT

First of all, I would like to thanks my supervisor, Prof Qumrul Ahsan who has spent time giving me advice and guiding me throughout this project. Without his supervision, this project will not progress as smooth as I have expected. Not only that, I would like to express my appreciation to Electronic Packaging Research Society (EPRS) for giving me the opportunity to study on this project and supplying the materials needed for it. Furthermore, I would like the thanks the lab technician who had helped and taught me to operate the machine available in the lab.

Besides that, I would also like to thanks my friends for sharing opinion and knowledge when I am facing difficulties on this project. I would like to specially thank some of my friends like Sin Yin, Huei Theng, Ung Hie, Hong Kheng and Alex Wong who have given me a lot of support and encouragement words during the project period. Last but not least, I would like to thanks my parents to providing support and encouragement all the time.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Ag	- Argentum/Silver
Au	- Aurum/Gold
BGA	- Ball Grid Array
Bi	- Bismuth
CNT	- Carbon Nano Tube
Co	- Cobalt
CTE	- Coefficient of thermal expansion
Cu	- Cuprum/Copper
EBSD	- Electron backscattered diffraction
ENEPIG	- Electroless Nickel Electroless Palladium Immersion Gold
ENIG	- Electroless nickel (Ni)-immersion gold (Au)
EPA	- Environmental Protection Agency
EPRS	- Electronic Packaging Research Society
Er	- Erbium
Ga	- Gallium
HASL	- Hot Air Solder Leveling
HS-CBP	- High Speed Cold Bump Pull
IC	- Integrated Chip
IMC	- Intermetallic Compound

JEITA	- Japan Electronics and Information Technology Industries Association
JIS	- Japanese Industrial Standard
LaB_6	- Lanthanum hexaboride
Ni	- Nickel
OSP	- Organic solder preservatives
Pb	- Plumbum/Lead
PCB	- Printed Circuit Board
Pd	- Palladium
RE	- Rare Earth
SAC	- Tin (Sn), Silver (Ag) and Copper (Cu) alloy
SAC105	- Sn-1.0%Ag-0.5%Cu
SAC205	- Sn-2.0%Ag-0.5%Cu
SAC305	- Sn-3.0%Ag-0.5%Cu
SAC305-0H-C	- SAC305 solder on coarse sample without aged
SAC305-0H-F	- SAC305 solder on fine sample without aged
SAC305-1H-C	- SAC305 solder on coarse sample aged for 1 hour
SAC305-1H-F	- SAC305 solder on fine sample aged for 1 hour
SAC305-3H-C	- SAC305 solder on coarse sample aged for 3 hours
SAC305-3H-F	- SAC305 solder on fine sample aged for 3 hours
SAC305-5H-C	- SAC305 solder on coarse sample aged for 5 hours
SAC305-5H-F	- SAC305 solder on fine sample aged for 5 hours
SAC387-0H-C	- SAC387 solder on coarse sample without aged

SAC387-0H-F	- SAC387 solder on fine sample without aged
SAC387-1H-C	- SAC387 solder on coarse sample aged for 1 hour
SAC387-1H-F	- SAC387 solder on fine sample aged for 1 hour
SAC387-3H-C	- SAC387 solder on coarse sample aged for 3 hours
SAC387-3H-F	- SAC387 solder on fine sample aged for 3 hours
SAC387-5H-C	- SAC387 solder on coarse sample aged for 5 hours
SAC387-5H-F	- SAC387 solder on fine sample aged for 5 hours
SAC357	- Sn–3.5%Ag–0.7%Cu
SAC387	- Sn-3.8%Ag-0.7%Cu
SEM	- Scanning Electron Microscopy
Sn	- Stannum/Tin
Std. Dev.	- Standard deviation
TEM	- Transmission Electron Microscopy
TGA	- Thermogravimetric
TiB_2	- Titanium diboride
UTS	- Ultimate Tensile Strength
WDS	- Wavelength Dispersive Spectroscopy
XRD	- X-Ray Diffraction
YS	- Yield strength
Zn	- Zinc

LIST SYMBOLS

%	- percent
μm	- micron
Å	- Angstrom
cm	- centimeter
g/cm^3	- gram per cubic centimeter
gf	- gram force
HV	- Vickers Pyramid Number
kgf	- kilogram force
mm	- millimeter
mN/s	- millinewton per second
ºC	- degree Celsius
ºC/min	- degree Celsius per minute
R_a	- average roughness
wt. %	- weight percent
λ_c	- cutoff wavelength

CHAPTER 1

INTRODUCTION

This chapter discusses about the purpose of this project and the scope of the research based on the background and problem faced by the society due to the usage of lead-based solder.

1.1 Research Background

Soldering is a joining process that does not melt the joining metals but the filler itself. Soldering is often used to mount the integrated chip (IC) onto printed circuit board (PCB) with a solder material. Hence this allows the electronic components to interact with one another. In the past, the lead-based was one of the most frequent used materials for soldering. The tin-lead (Sn-Pb) alloy was often chosen from the lead-based solder.

According to Leng *et al.* (2008), the Sn-Pb has been commonly used to join electronic components to circuit board due to its low melting point and high wetting characteristic on some substrate platings such as Cu, Pd, Ag and Au. Sylvester (2011) mentioned that the eutectic solder with 37% Pb – 63% Sn is ideal due to their ability it changes to liquid state once it is melt. The low soldering temperature reduces the damage on the components on the circuit board.

According to Suganuma (2001), the lead-based solder material has caused increasing environmental problem and health issue. Many researchers said that the electronic product which contains lead will end up in the solid waste landfills after their useful life. These disposed products will then enter the ground water stream and soon leads to animal or human food chain. Abtew and Selvaduray (2000) stated that lead can strong binds the proteins in the body when it starts accumulate as time passes by. It may cause delays in neurological and physical development, nervous and reproductive system disorders, cognitive and behavioral changes and other hazards. Hence lead and its compounds have been considered one of the top 17 chemicals that give most threat to the human society by the Environmental Protection Agency (EPA). Not only that, the Sn-Pb is unable to form intermetallic compounds (IMC) when soldered on the substrate. The IMC can act to prevent the dislocation of atoms. Hence the creep resistance for Sn-Pb is rather weak.

An alternative lead-free solder is introduced to overcome the weakness of lead-based. According to Kotadia *et al.* (2014), an ideal new solder has to able to improve the wettability of the solder, quick IMC formation, improve the ductility of tin, has a melting temperature around 183ºC, good mechanical properties, and low chance of tin whiskers formation. Suganuma (2001) mentioned that the most common solder candidate used is the Sn-Ag-Cu alloy family, followed by some other candidates such as Sn-Cu, Sn-Zn-Bi and Sn-Bi-Ag. Since lead-free solder requires higher soldering temperature, the substrate dissolution and rate of intermetallic growth is expected to be greater than the lead-based solder.

1.2 Problem Statement

Miyazawa and Ariga (2001) mentioned that the lead-free solder has to be improved further to be at least on par with the lead-based solder in term of metallurgical properties. Despite the presence of over 70 lead-free alloys, there is not any which can perfectly replace the lead-based. Suganuma (2001) stated that the cost of lead-free solder is almost two to three times higher than the Sn-Pb solder. Furthermore, most lead-free solders still cannot surpass the wetting ability of Sn-Pb on Cu substrate. Hence, numerous researches have been done to find the suitable replacement based on its mechanical properties, melting points and wettability of the solder material. According to Wong *et al.* (2006), the lead-free alloys has higher tendency to induce higher stress at the solder and intermetallic interface during deformation rate events due to higher yield strength and modulus.

Kotadia *et al.* (2014) mentioned that there has also been effort in introducing addition of element into the alloy to obtain better properties of solder. For example, Zhang *et al.* (2012) had tried the adding the rare earth element, Er in SnZn solders. It could improve the oxidation resistance and mechanical properties of the solder. On the other hand, Babaghorbani *et al.* (2008) found that addition of too much reinforcement may degrade the mechanical and electrical properties. Miyazawa and Ariga (2001) stated that the results obtained from the researchers are still looking for improvement on the lead-free solders.

The mechanical properties and metallurgy of the solder joint play an important role in determining the reliability. Choi and Lee (2000) mentioned that it is important to study the IMC between the solder and substrate as it represents the reliability of the solder joint. Despite of the fact IMC can enhance the creep resistance, it makes the joint less ductile and tough as the compounds tend to be brittle in nature. The interfacial morphology of the joint can be controlled by the soldering condition. Hence, the soldering condition should be studied well to obtain the ideal condition giving a good solder joint.

Eu *et al.* (2007) has compared IMC microstructure and mechanical properties between Sn-3.8%Ag-0.7%Cu (SAC387) and Sn-3.5%Ag. Eu *et al.* (2007) found that the Sn-3.5%Ag has less intermetallic brittle failure rate compared to SAC387. On the other hand, Eu *et al.* (2007) compared the mechanical strength of SnAgNiCo and SAC387. They found out that the SnAgNiCo gives better solder joint strength than the SAC387 as well. However, there are not many researches study on the comparison between SAC with different compositions. Thus, these two different compositions of the Sn-Ag-Cu solder were used in this study.

Moreover, based on previous researchers, there are also limited studies carried out on bond characteristic created from the surface roughness between the solder and the substrate. The ageing time was also varied to study the effect on the microstructure and mechanical properties.

1.3 Objectives

The objectives of the research are:

- To deposit SAC305 and SAC387 solders on copper substrate by varying surface roughness and ageing time.
- To determine IMC hardness of as deposited and aged lead-free solder material on copper substrate with different surface roughness using micro-Vickers hardness test.
- To analyze the morphology of IMC formed between lead-free solder and copper substrate by SEM and XRD.