UNIVERSITI TEKNIKAL MALAYSIA MELAKA

EFFECT OF SUBSTRATE SURFACE CONDITION ON THERMAL CYCLING BEHAVIOUR OF LEAD-FREE SOLDERS

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

by

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Engineering Material) (Hons.). The member of the supervisory is as follow:

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(PROF. DR. QUMRUL AHSAN)

ABSTRAK

Pateri tanpa plumbum dikenali sebagai bahan generasi moden yang diperkenalkan untuk penggantian pateri mengandungi plumbum atas sebab mesra alam. Dalam bidang industri pembungkusan elektronik, kualiti pateri sendi bukan sahaja bergantung kepada bahan pateri, tetapi termasuk kemasan pemukaan juga. Kajian ini akan membincangkan tentang mikrostruktur analisis dan pencirian bagi kesan dan penjejasan oleh kitaran haba kepada pateri tanpa plumbum dengan kemasan pemukaan yang beza. Bahan pateri yang digunakan adalah SAC 305 yang terdiri daripada timah, perak, dan tembaga. Kemasan pemukaan yang termasuk dalam kajian ini adalah tembaga, timah rendaman, dan tanpa elektrik nikel dengan emas rendaman. Kajian ini bertujuan untuk mengaji mikrostruktur sendi pematerian dan sebatian antara logam terjadi dalam kemasan pemukaan yang beze selepas kitaran haba. Dengan ini, impak yang dibawa oleh sebatian antara logam yang terhasil kepada prestasi dan hayat perkhidmatan sendi pematerian dapat disiasat dan dikenalpastikan. Kesan daripada kemasan pemukaan dan sebatian antara logam kepada retak inisiasi dan pembiakan oleh sebab kitaran haba akan dianalisiskan dalam kajian ini. Selepas ujian kitaran haba, sampel akan dibuat keratan rentas, dan seterusnya pengisaran dan penggilapan. Nanoindentation akan dijialankan untuk membandingkan dan memeriksa kesan daripada kitaran haba kepada sampel dengan yang diterima. Kemudian, morfologi sampel akan didedahkan dengan pengimbasan elektron mikroskop untuk mengaji kelakuan perambatan retak dalam sendi pematerian. X-ray pembelauan analisis akan dilaksanakan untuk mengetahui kesan penghasilan sebatian antara logam terhadap sendi pematerian. Sebagai tambahan, tenaga serakan x-ray akan dijalankan terhadap sampel untuk mengetahui komposisi dan unsuran sebatian antara logam. Berdasarkan analisis yang diperolehi, ENIG menunjukkan impak yang paling serius diakibatkan

daripada kitaran haba dan ImSn pula menunjukkan kecenderungan yang paling tinggi untuk perkembangan IMC. Kajian ini juga menunjukkan retak fenomena berlaku semasa kitaran haba yang rendah dan mekanismenya dikaji.

ABSTRACT

Lead-free solder is a new generation material which introduced for the replacement of conventional lead containing solder in the purpose of environmental friendly. In electronic packaging industry, the reliability of solder joint not only depends on the solder material but include the surface finish. This study will focus on the microstructural analysis and characterization of the effect of thermal cycling behaviour to the lead-free solder with different types of surface finish. The solder material used is SAC 305 which composed of tin, silver, and copper. The surface finishes included in this study were bare copper, immersion tin, and electroless nickel immersion gold. The main aim was to determine the microstructure of the solder and the intermetallic compounds formed in different types of surface finish after thermal cycling test is applied which affecting the performance and lifetime of solder joint. The effect of surface finish and the intermetallic compounds to the crack initiation and propagation behaviour in the influenced of thermal cycles is analyzed in this research. After thermal cycling test, the samples were cross sectioned, grinded and polished. Nanoindentation is carried out to compare and examine the effect of thermal cycling to the samples with the as-received samples. Then, the morphology of the sample was reveal under Scanning Electron Microscopy in order to inspect the crack propagation behaviour in the solder. X-ray diffraction analysis is performed to understand about the effect of intermetallic compound formation in the solder joint. In addition, the samples undergo Energy Dispersive X-ray for compositional and elemental analysis of intermetallic compound layer. From the analysis, ENIG displayed most serious impact from thermal cycling and ImSn shows highest tendency for IMC to grow. The study also shows that the cracking phenomena happened in low thermal cycles and the mechanism is analyzed.

DEDICATION

To my beloved parents, siblings and friends for their love and support

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First and foremost, I would like to express my utmost gratitude to my supervisor, Prof Qumrul Ahsan for his guidance, advice, concern, understanding and patience throughout the research period. His supervision has helped a lot in the progression of this final year project. I am indeed very grateful to be under his supervision. Besides, I would like to express my appreciation to Electronic Packaging Research Society (EPRS) for provided me an opportunity to participate in this project. I am sincerely expressing my appreciation to Redring Solder Sdn. Bhd., who sponsored the raw material to me and initiated this project. In addition, I would also like to thanks to Prof Dr. Azman and Puan Maria from the Institute of Microengineering and Nanoelectronics (IMEN), who have contributed a lot in coordination of this project and providing their valuable experience.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

Ag	-	Silver
Au	-	Gold
BGA	-	Ball Grid Array
Cu	-	Copper
EDX	-	Energy dispersive X-ray
ENIG	-	Electroless Nickel/Immersion Gold
I/O	-	Input/Output
IMC	-	Intermetallic Compound
ImSn	-	Immersion Tin
Ni	-	Nickel
Pb	-	Lead
PCB	-	Printed circuit board
SAC	-	Tin, Silver, Copper (Sn, Ag, Cu)
SEM	-	Scanning electron microscope
Sn	-	Tin

CHAPTER 1

INTRODUCTION

This chapter discusses about the introduction of this project and gives a basic overview to the purpose and scope of this research.

1.1 Background

Soldering is a metallurgical joining method using a filler metal known as solder with a melting point below 315°C and commonly applied in electronic packaging industry. With excellent combination properties, SnPb solder in near eutectic composition has been widely used in electronic interconnections for several decades. However, the recent legislative restrictions induced by the worldwide concerns about the potential environmental contamination effects of lead, and thus the elimination of lead has become a focused goal in recent years. Lead-free solders typically with more alloying constituents, have melting temperatures 20-35°C higher than the conventional SnPb solder (183°C), results in increased difficulty of metallurgical issues to control reliability and narrowed process parameters. Solder interconnection reliability has been one of the top concerns due to the massive amount and tiny size of interconnections.

The service reliability of a solder interconnection is determined by many factors, including the solder microstructure and morphology, creep deformation, thermo-mechanically induced recrystallization, brittle intermetallic fracture, thermally mismatch either in local or global happened due to the difference in coefficient of thermal expansion, or combinations thereof (Grossmann & Zardini, 2011). Therefore, the solder joint reliability not only depends on the solder joint alloy itself, but a relationship between the solder material and the surface finish or known as metallization of the printed circuit board. The surface finish affects the wetting and microstructure of the solder joint in terms of the intermetallics formed, which served as the interconnection (Pan, Ph, & Shaddock, 2004).

This project is an industrial driven research provided and spearheaded by Electronic Packaging Research Society (EPRS) for final year project. In this project, the crack propagation and intermetallic compound (IMC) formation were investigated using the solder material provided by Redring Solder (M) Sdn. Bhd. Solder includes SAC 305, which soldered on three types of surface finish test board that were copper substrate, surface finished with immersion tin (ImSn), and electroless nickel/immersion gold (ENIG). The crack growth mechanism and propagation in the solder will be examined and the effect of crack propagation on the intermetallic compound is studied with the thermal cycling test of the characteristic temperature range of 0°C to 100°C to represent the service condition. Then, material characterization will be conducted on the specimen to reveal the type of intermetallic compound existed in the solder and analyze morphology of the solder in microscopic level. Additionally, a comparison will be made with the experimental results to characterize the effect of surface finish to the crack propagation in the solder.

1.2 Problem Statement

The study of crack propagation behaviour on different type of solder intermetallic plays an important role in contribution to the long-term stability of the solder joints and development of new solder material. Temperature is an important factor affecting the change of solder intermetallic and alters the service life of solder. The IMC growth in different duration under change in thermal stress and the crack propagation is analyzed to determine the effect of different IMC lead to the morphology of the solder after crack propagated. Most of the studies do not provide a systematic understanding in the detail micro-structural change along the process. With increasing demand of lead-free soldering in the market, this project will contribute to the manufacturing industries by demonstrate the crack propagation in the solder at different duration along the process and thus provide detail understanding of the failure mechanism of lead-free solder in reliability engineering.

1.3 Objective

1. To characterize the intermetallic formed at lead free solder and substrate with different surface finishes by optical and scanning electron microscopy and x-ray diffractometry.

2. To determine the mechanical properties of solder and different surface finishes of as received solder and solders with different thermal cycles by nanoindentation method.

3. To analyze the effect of surface finishes and intermetallic compound on the crack initiation and propagation behaviour of solders at different thermal cycles by scanning electron microscopy and x-ray diffractometry.

1.4 Scope of Study

The scope of the study is to examine the mechanism of crack propagation caused by thermal mismatch on the solder intermetallic for different types of surface finishes on copper substrate. The solder material involved is SAC 305, with three types of lead-free surface finish include bare copper, immersion tin, and electroless nickel/immersion gold on copper substrate. This study focused on the morphology of the solder intermetallic corresponding with different duration of thermal cycles. Then, the solder intermetallics formed in the solder are characterized and quantified. The mechanism and growth of crack propagation on the intermetallics is explained in this project by comparing the surface condition of as-received samples with the samples after thermal cycling.

1.5 Project Outline

Chapter 1 includes the basic introduction of this project and emphasizes about the reasons and objectives of conducting this research. Then, Chapter 2 consists of the literature review which explains about the critical points of current knowledge in related to the project. Followed with Chapter 3, the methodology to establish this project and procedure to conduct test and experiment is explained. Chapter 4 includes result and discussion which consists of the data obtained in the test and analyzes the data with theoretical aspect. Chapter 5 denotes conclusions and recommendations which summarize the finding of this research and give beneficial suggestion for future investigation.

CHAPTER 2

LITERATURE REVIEW

This chapter gives an overview on previous research work in various areas which are relevant to this project.

2.1 Introduction to Soldering

Soldering is a metallurgical joining process using a filler metal which known as solder with a relatively low melting point compared with the printed circuit board and electronic components, typically a melting point below 315°C (H.Manko 2001). Previously, lead-containing solders have been widely used in the electronic packaging industry due to its low melting point at near eutectic composition such as 60Sn40Pb, 63Sn37Pb (Zhao et al. 2009). However, the potential environmental contamination effects and hazardous effect to human health has raised global awareness to the usage of lead in solder. After July 1, 2006, lead elimination is enforced with the control of RoHS by the European Union directives on Waste Electrical and Electronic Equipment (WEEE) (Zhang et al. 2011). This enforcement has propelled the research for Pb-free solder replacement results in finding of Sn-Ag-Cu (SAC) type alloys as standard lead-free solders. This lead-free solder, SAC type alloys have been used at

almost 70 percents in electronic assemblies industry based on the market research (Kolenák 2013).

In electronic packaging industries, there are two major soldering processes known as wave soldering and reflow soldering involved in surface mount technology. For semiconductors or chips without external packaging, flip-chip technique is used to mounting them directly on a substrate (John W.Evans et al. 2005). Flip chip technology is widely used for electronic interconnections as it offer high number of I/O connections, cost effective and high reliability as mentioned by Magill and Lau, 1996 (Hsiao & Duh 2006).

2.1.1 Types of Soldering Process

2.1.1.1 Wave Soldering

Wave soldering is a type of continuous flow soldering by conveying the loaded PCB into contact with wave solder that applied to the bottom of the solder pot. The circuit board is placed with electronic components, and then placed in the soldering machine. The bottom of the board passed through a fluxing operation, followed with pre-heating to activate the flux. Then, the bottom of the board is passed through a molten solder wave and followed with cooling (H.Manko 2001).