UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ROLE OF INTERMETALLIC COMPOUND ON THERMAL CRACK PROPAGATION OF LEAD FREE SOLDERS

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

by

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DECLARATION

I hereby, declared this report entitled 'The Role of Intermetallic Compound on Thermal Crack Propagation of Lead Free Solders' is the results of my own research except as cited in references.

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirement 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

Kecenderungan perkembangan dalam komponen elektronik dipengaruhi oleh peningkatan prestasi dan kebolehpercayaan pematerian. Penggantian konvensional utama timah (SnPb) pateri kepada pateri tanpa plumbum telah mengubah kebolehpercayaan sesuatu komponen. Pengaloian telah dibangunkan untuk membawa bahan pateri tanpa plumbum untuk mencapai hampir sedekat tahap kebolehpercayaan yang menggunakan pateri konvensional. Walau bagaimanapun, isu kebolehpercayaan adalah pada mekanisme kegagalan pateri tanpa plumbum. Kajian ini akan memberi tumpuan kepada analisis mikrostruktur dan pencirian kelakuan pertumbuhan sebatian antara logam yang di pateri tanpa plumbum dengan pelbagai jenis kemasan permukaan. Bahan pateri yang digunakan adalah SAC 305 yang terdiri daripada timah, perak dan tembaga. Kemasan permukaan termasuk dalam kajian ini terdiri daripada tembaga, timah rendaman, dan tanpa elektrik emas nikel rendaman. Tujuannya adalah untuk menyiasat sebatian antara logam terbentuk dalam pelbagai jenis kemasan permukaan selepas ujian kitaran haba pada 900, 1200 dan 1500 kitaran digunakan dalam suhu 100ºC di mana dapat memberi kesan kepada kebolehpercayaan sambungan pateri. Pertumbuhan sebatian antara logam dalam kemasan permukaan yang berbeza dianalisis dalam kajian ini. Selepas ujian kitaran haba, sampel telah dijadikan keratin rentas, dikisar dan digilap. Kemudian, morfologi sampel itu didedahkan di bawah Mengimbas Mikroskopi Elektron untuk menganalisis pembentukan sebatian antara logam. Pengukuran menunjukkan ImSn menunjukkan ketebalan tertinggi sebatian antara logam berkembang sehingga 11µm. Walaubagaimanapun, sebatian antara logam pada sampel tembaga adalah merupakan yang terendah pada ukuran 4.5µm. Selain itu, kajian ini menunjukkan mengganggu fenomena yang berlaku dalam sampel kemasan permukaan yang berbeza dan mekanisme itu dianalisis.

ABSTRACT

The tendency of development in electronic components is influenced by performance enhancement and the reliability of the soldering. The replacement of conventional tin lead (SnPb) solder to lead free solder have changed the reliability of the component. Alloying constituents have been developed for lead free solder materials to achieve almost as close a reliability level as using conventional solders. However, the issue of reliability is on the failure mechanisms in lead free solder interconnection. This study focused on the microstructural analysis and characterization of the intermetallic compounds growth in 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 research were bare copper, immersion tin, and electroless nickel immersion gold. The aim was to investigate the intermetallic compound growth in different types of surface finish after 900, 1200 and 1500 cycles of thermal cycling test is applied at 100ºC of cyclic temperature in which affecting the solder joint reliability. After thermal cycling test, the sample were cross sectioned, grinded and polished. Then, the morphology of the sample was reveal under Scanning Electron Microscopy to analyze the formation of intermetallic compounds. The measure shown that immersion tin surface finish produced the highest thickness of intermetallic compounds growth up to 11µm. However, intermetallic compound in copper surface finish shows the lower thickness about 4.5µm. Besides, this research show voiding phenomena happened in the samples of different surface finish and its mechanism is analyzed.

DEDICATION

To my beloved parents, sibling and friend for their love and supports.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

Ag - Silver

Au - Gold

BGA - Ball Grid Array

Cu - Copper

ENIG - Electroless Nickel Immersion Gold

IMC - Intermetallic Compound

ImSn - Immersion Tin

Ni - Nickel

Pb - Lead

PCB - Printed Circuit Board

SAC - Tin, Silver, Copper (Sn, Ag, Cu)

SEM - Scanning Electron Microscopy

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

Recent years, lead free solder alloy has the trend due to widely applied in the electronic interconnections. The past uses of tin lead (SnPb) resulted in a measurable increase of lead in the environment. Consequently along with the market forces, world environmental legislation had seek for initiatives that is driving the advantageous of lead free solders. However, as a consequence of changing the conventional solder alloy resulted in a significant changes to the soldering process. Basically, the attention is on the high melting temperatures associated with lead free solder alloy. Hence, due to changes of these process, the concerns is on the reliability of the solder joint interconnection. Furthermore, solder interconnection act an importantly in electronics packaging due to its role to serve both as electrical components interconnections in chip board, and as a mechanical platform for components.

The tendency of development in electronic components is influenced by performance enhancement and the reliability of the soldering. However, a number of issues regarding the reliability of solder joint interconnection is focusing to the interfaces between molten solder and substrate surface. This is due to the microstructure formed due to reaction rate between solder-substrate interfaces. There are several factor that influenced the reliability of soldering. However, the researchers shown that the intermetallic compound (IMC) layer formed between the solder and the substrate as the most important factor that influenced the solder joint reliability.

Even though it is proved that the formation of an intermetallic compound layer provides a good bonding between the solder and substrate, however, IMC have its main disadvantage which is typically be the most brittle part in the solder interconnection. Hence, as the result, the solder joints become even smaller in size, the naturality of IMC and its impact on solder joint reliability becoming the most concern part with the introduction of new lead-free solder alloy systems (Salam, 2005). However, the reliability of solder joint not only concerning on the intermetallic compound formed. The service reliability of the solder joint is determined by many factors including the solder microstructure and morphology, creep deformation, thermo-mechanically induced recrystallization and thermal mismatch regarding to the differences in coefficient of thermal expansion or combinations thereof (Grossman & Zardini, 2011).

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 SAC305 which soldered with three types of surface finish test board that were copper, immersion tin (ImSn) and electroless nickel immersion gold (ENIG) on copper substrate.

1.2 Problem Statement

The study of the different types of intermetallic compound (IMC) formed in different type of solder joints is important as to investigate the crack propagation behavior due to the issue on reliability of solder joint interconnection and the performance of electronic appliances. The intermetallic compound is the actual bond formed in soldering from the diffusion of solder alloy and substrate. In addition, consequence from the brittle property of intermetallic compound effected the solder interconnection. This is caused by a strong stress concentration during the thermal cycles. Hence, the cracks were found to initiate and propagate near the intermetallic compound layers. The crack propagation is analyzed to understanding the role of the different IMC on the morphology of the solder joints after crack propagated. Furthermore, this project will provide an understanding of the failure mode mechanism of lead free solder particularly on the IMC layer morphology and the role of the IMC formation and growth rate on the thermal crack propagation of lead-free solder.

1.3 Objectives

1. To measure the growth of intermetallic compounds at the solder and the substrate interfaces under different thermal cyclic conditions.

2. To characterize the role of intermetallic compound on the crack initiation and propagation behavior at different thermal cyclic conditions by scanning electron microscopy.

1.4 Scope of Study

The scope of study is to examine the mechanism of crack propagation caused by thermal mismatch on the solder intermetallic for different type of surface finishes on copper substrate. The solder material involved is SAC 305, when three types of lead free surface finish include copper (Cu), immersion tin (ImSn), and Electroless Nickel Immersion Gold (ENIG) on copper substrate. This study focused on the morphology of the solder intermetallic corresponding with different duration of thermal cycles. Then, the solder intermetallic formed in the solder are characterized and analyzed. The failure mechanism in the solder interconnection is explained in this project by comparing the microstructure 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 related to the project. Followed by Chapter 3, the methodology to establish this project and procedure to conduct test and experiment is explained. Next, Chapter 4 displays all the observation and result from experiments. Furthermore, discussion were made and explained through this chapter. Lastly, Chapter 5 concluded the results of this research and recommendations for further study on this research.

CHAPTER 2

LITERATURE REVIEW

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

2.1 Soldering

In the electronic materials trending world, soldering plays an important role in the assembly and interconnection of the silicon die or chip. The soldering process has been a fundamental aspect in the realization of all electronic products since the commencement of the electronic age, and it is anticipated that it will remain the primary assembly and interconnection technology for some time to come (Kotadia et al., 2014). Soldering uses molten filler metal to wet the surfaces of a joint, and to form metallurgical bonds between two metal parts. The melting temperature of the filler metal is lower than 450ºC. The soldering process can be depicted and can be roughly divided into three stages: spreading, base metal dissolution, and formation of an intermetallic compound layer (Lee, 2011).

2.2 Solder Materials

Lead (Pb) based solders have been the cornerstone technology of electronic interconnections for many decades. However, with legislation in the European Union and elsewhere having moved to restrict the use of Pb, it is imperative that new Pb-free solders are developed which can meet the long established benchmarks set by leaded solders and improve on the current generation of Pb-free solders such as SAC105 and SAC305 (Kotadia et al., 2014). It was reported that lead-free solder joints had fine and stable microstructures due to the formation of small-dispersed particles and thus had higher shear strength than SnPb solders (Arulvanan et al., 2006).

2.2.1 SAC Alloys

Today, SnAgCu (SAC) soldering alloys are becoming one of the most favored lead-free soldering alloys. SAC alloys have been studied extensively in terms of material properties, mechanical behavior, solder-substrate interactions, thermomechanical fatigue life analysis, etc. (Mayyas et al., 2013).

2.3 Surface Finish

Based on the view of Siewiorek et al., (2001) surface finish of the substrate can be a critical factor that changed the quality of the solder joint interconnection. Solder intermetallic compound formed as a critical interface between the electronic component and the substrate, as a metallurgical process and evidence of chemical bonding happened. The main functions of this surface finish are to protect the exposed copper circuitry from oxidation and a solderable surface which enhanced wetting. In the other words, Jasbir has emphasized the statement of Siewiorek by stated that the surface finish not only can provide good solderable surface but minimize the copper dissolution during assembly operation so that the growth of intermetallic can be controlled. In addition, the growth of intermetallic has to be controlled in order to prevent the embrittlement from happened in the solder joint (Bath, 2007).

Surface finish can be described as a thin coating on the outmost layer of PCB which known as Solder Mask Over Bare Copper (SMOBC). It will dissolve into solder paste during reflow or wave soldering process. There is a number of surface finishes that commonly implemented in industries. However in this project, the surface finishes involved are copper substrate (Cu), Immersion Tin (ImSn), and Electroless Nickel Immersion Gold (ENIG).