INTERFACIAL REACTIONS BETWEEN LEAD- FREE SOLDERS AND ELECTROLESS NICKEL/ IMMERSION GOLD (ENIG) SURFACE FINISH

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To my beloved wife and family. Thank you for your endless love and support……..

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ABSTRACT

The growth of advanced electronics has brought human to new eras which allow human to fully utilize the innovation of technology in daily applications. As semiconductor industry develops rapidly, flip chip based electronic packaging faces new challenges for packaging design and performance to meet far more stringent requirements on package size, quality, performance and reliability. This research has been made to study the effect of nickel additions on the interfacial reactions between Sn-3.0Ag-0.5Cu lead-free solder and electroless nickel (boron)/ immersion gold (ENIG) surface finish. The effect of isothermal ageing treatment on solder joints after reflow soldering, at temperatures of 150°C and 175°C for 250, 500 and 1000 hours, is also investigated. Several material characterization techniques including optical, scanning electron microscopy, energy dispersive x- ray analysis and image analysis were applied to investigate the intermetallic in terms of morphology, composition, thickness and distribution. From the study, it was observed that the IMC growth is influenced by ageing temperature and ageing duration where the thickness of intermetallic compounds increases with ageing. The result also showed that solder with Ni addition formed thinner IMC after reflow and ageing up to 1000 hours. The EDX analysis shows that the IMC formation and growth in the solder joints led to the formation of several types of IMC with different morphologies and chemical composition.

ABSTRAK

Pertumbuhan elektronik canggih telah membawa manusia ke era baru yang membolehkan manusia memanfaatkan sepenuhnya inovasi teknologi dalam aplikasi seharian. Dengan perkembangan industri semikonduktor yang pesat, pembungkusan elektronik jenis *flip chip* menghadapi cabaran baru dalam rekabentuk dan prestasi pembungkusan untuk memenuhi keperluan yang jauh lebih ketat pada saiz pakej, kualiti, prestasi dan kebolehpercayaan. Penyelidikan ini telah dilakukan untuk mengkaji kesan penambahan nikel terhadap tindakbalas antara *solder* tanpa plumbum Sn- 3.0Ag- 0.5Cu dengan kemasan permukaan nikel tanpa elektrod/ rendaman emas (ENIG). Kesan rawatan penuaan pada sambungan *solder* selepas proses pematerian *reflow* pada suhu 150 °C dan 175 °C selama 250, 500 dan 1000 jam juga diselidik. Beberapa teknik pencirian bahan termasuk optik mikroskop, *scanning electron microscopy,* analisis *energy dispersive x- ray* dan analisis imej digunakan untuk menyiasat intermetalik dari segi morfologi, komposisi, ketebalan dan taburannya. Dari kajian ini, didapati bahawa pertumbuhan *IMC* dipengaruhi oleh suhu dan tempoh penuaan di mana ketebalan sebatian intermetalik meningkat dengan rawatan penuaan. Keputusan kajian juga menunjukkan *solder* dengan penambahan Ni membentuk lapisan *IMC* yang nipis selepas *reflow* dan penuaan selepas 1000 jam. Analisis *EDX* menunjukkan pembentukan *IMC* dan pertumbuhan dalam sambungan *solder* menyebabkan pembentukan beberapa jenis *IMC* dengan morfologi dan komposisi kimia yang berlainan.

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CHAPTER I

INTRODUCTION

1.1 Introduction

Flip chip technology is nothing new in the microelectronic field. This idea was initiated in early 1970 by IBM, one of the leading players in the electronic packaging market which believed it is a promising option for future electronic packaging. However the complication in the packaging assembly processes and high cost of wafer bumping process has given way to wire bonding technology to continue dominating the semiconductor packaging business. Recently, market demand in more complexity of the electronic product design and its functionality has driven the application of flip chip technology as people foresee the wire bonding technology has reached its limit. In fact, most electronic packaging manufacturers had tipped flip chip bonding to be the preferable interconnects bonding technology which will steer the rapid growth of the electronic devices.

In earlier days, flip chip bonding technology employed solder as the interconnection material to connect dies to packaging substrates and lead tin solder alloy has dominated the assembly process due to its low melting temperature and excellent wetting characteristics toward several surface finishes. However, the

toxicity of lead which endangers the environmental and human health has urged the manufacturers to develop new lead-free solder to replace tin- lead solder. Surface finish is another variable that must be taken into account during metallurgical bonding. The purpose of surface finish is to protect the substrate base metal from oxidizing and limits the diffusion of solder into underlying metal. With various substrates surface finishes being developed, electroless nickel/ immersion gold (ENIG) surface finish has steadily increased in preference over the years because it offers better planarity, improved corrosion resistance to the base material and excellent wettability. From application point of view, the ENIG surface finish has become the preferable option for flip chip products.

During interconnection, chemical reactions occur between solder and substrate underlying material. A thin and continuous intermetallic compound (IMC) layer will be formed after solidification process and it is an essential requirement for flip chip interconnects to ensure a good bonding. Nevertheless, thick IMC layer may deteriorate the reliability of solder joint due to their brittle behaviour. Hence, there is a need to understand the interaction and phase evolution in solder joint to establish the engineering database.

1.2 Significance of Study

Electroless nickel plating is an important process in electroless nickel/ immersion gold (ENIG) surface finish. The electroless nickel processes are grouped as nickel with phosphorus (Ni-P), nickel with boron (Ni-B) and pure nickel. Electroless nickel with phosphorus is standard practice in semiconductor industry because of its excellent manufacturability and low cost. Furthermore, it has been well established and has demonstrated the capability to fulfill the electronic packaging quality and reliability. Recently, electroless nickel with boron deposition also

received attention as an alternative due to its superior mechanical and chemical properties. Therefore, people start to study the interfacial reaction between solder and Ni- B layer toward the reliability of solder joint since it is one of the most crucial criteria in microelectronic packaging. As the interaction yet to be established, it is an interesting research to have better understanding on these interconnects.

1.3 Objectives of Research

One of the main objectives of this project is to investigate the types and morphology of intermetallic compounds which formed between Sn- Ag- Cu (lead-free) solders and Electroless Nickel (Boron)/ Immersion Gold surface finish after reflow soldering process and solid state ageing treatment.

The second objective is to evaluate the effects of solid state ageing treatment on IMC formation and growth. Under this treatment, there are two main parameters that will be considered: ageing temperature and ageing duration.

1.4 Scopes of Research

The copper substrates are plated with Electroless Nickel (Boron) / Immersion Gold (ENIG) surface finish with 1 to 3% of Boron content. Different types of lead free solders (Sn- Ag3.0- Cu0.5, Sn- Ag3.0- Cu0.5 with 0.05% nickel doping and Sn-Ag3.0- Cu0.5 with 0.1% nickel doping) are used with size of 500μm diameter solder balls mounted on the substrate and reflow soldering process is conducted. The study

also focuses on isothermal ageing treatment at different temperatures (150°C and 175°C) with 250 hours, 500 hours and 1000 hours. Characterization is done on the IMC formation after reflow soldering process and IMC growth after ageing to determine types, morphology and thickness of IMC.

1.5 Structure of Thesis

This thesis consists of five chapters. Chapter 1 is the introduction of this thesis where objectives and scope of research are defined. Chapter 2 is the review of electronic packaging and types of interconnection technologies available in current market. This chapter also includes some of the common used surface finishes and solders in the electronic packaging market, soldering techniques and intermetallic compound formation at the interface of solder joints. Chapter 3 states the detailed of experimental setup of this research include the material preparation, soldering and characterization methods. Chapter 4 contains the results and discussion obtained from the experimental work. Chapter 5 is the conclusion of the thesis based on the results and discussion of the work. Lastly, chapter 6 states some recommendations for future work.