INTERFACIAL REACTION AND CORROSION BEHAVIOUR BETWEEN SAC305 AND SAC307 SOLDER ON ELECTROLESS NICKEL/IMMERSION SILVER (ENImAg) AND ELECTROLESS NICKEL/IMMERSION GOLD (ENIG) SURFACE FINISH

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ABSTRACT

Tin-Silver-Copper (SAC) solder was recognized as the preferable for lead-free solder composition, while electroless nickel/immersion gold (ENIG) was recognized as the most popular surface finish for printed circuit board (PCB). However, ENIG has disadvantages, including the high cost of gold (Au) material and the black pad issue on the surface coating. Therefore, this study aims to investigate the interfacial reaction and corrosion behaviour between Sn-3.0Ag-0.5Cu (SAC305) and Sn-3.0Ag-0.7Cu (SAC307) solder on electroless nickel/immersion silver (ENImAg) and ENIG surface finish through laser soldering process. Laser soldering was chosen because of its good performance. ENImAg was chosen as an alternative for ENIG due to its low cost and no black pad issue reported on surface coating. The samples were subjected to isothermal ageing at 150°C for different ageing duration 250, 500, 750 and 1000 hours. Then polarization test was conducted, and potassium hydroxide (KOH) was used as an alkaline solution that acted as melting battery. The result revealed that SAC/ENImAg and SAC/ENIG showed the intermetallic compound (IMC) grain microstructure was constantly increased when the percentage of Cu in solder paste increases. The different Cu composition is chosen to know the effect of Cu composition on IMC. The IMC formation after laser soldering and the ageing process was detected as $(Cu, Ni)_6Sn_5$, $(Ni, Cu)_3Sn_4$, and Ag_3Sn. The observation showed that ENIG's IMC thickness and microstructure is thinner and smaller than ENImAg. During the ageing process, the IMC thickness for both surfaces gradually increases with the ageing time. Regarding corrosion rate analysis, SAC305/ENIG is much better than SAC305/ENImAg. However, both surface finish still in acceptable range for corrosion rate where the reading is not more than 0.1 mm/year. This research discovered that ENImAg can be an alternative surface finish to ENIG.

ABSTRAK

Pateri Tin-Perak-Tembaga (SAC) diiktiraf sebagai pilihan terbaik untuk komposisi pateri tanpa plumbum, manakala nikel/emas rendaman tanpa elektro (ENIG) diiktiraf sebagai kemasan permukaan popular untuk papan litar bercetak (PCB) dalam industri elektronik. Walau bagaimanapun, ENIG mempunyai kelemahan iaitu pada kos bahan emas (Au) dan juga isu pad hitam pada salutan permukaan. Oleh itu, kajian ini bertujuan untuk menyiasat tindak balas dan kesan kakisan antara Sn-3.0Ag-0.5Cu (SAC305) dan Sn-3.0Ag-0.7Cu (SAC307) pateri pada nikel tanpa elektro/perak rendaman (ENImAg) dan ENIG melalui proses pematerian lasik. Pematerian lasik dipilih kerana prestasi yang baik. ENImAg dipilih sebagai alternatif kepada ENIG kerana kos yang murah dan tiada isu pad hitam dilaporkan pada salutan permukaan. Sampel kemudian dibiarkan pada suhu 150 °C pada tempoh masa penuaan yang berbeza iaitu 250, 500, 750 dan 1000 jam. Kemudian, ujian polarisasi dilakukan menggunakan kalium hidroksida (KOH) sebagai larutan alkali yang bertindak sebagai cairan bateri. Hasilnya dilihat bahawa SAC/ENImAg dan SAC/ENIG menghasilkan struktur mikro butiran sebatian antara logam (IMC) sentiasa meningkat apabila peratusan Cu dalam pes pateri adalah tinggi. Perbezan komposisi Cu dipilih untuk mengetahui kesan komposisi Cu terhadap IMC. Pembentukan IMC selepas permeterian lasik dan proses penuaan dikesan sebagai $(Cu, Ni)_6Sn_5$, $(Ni, Cu)_3Sn_4$, dan Ag_3Sn. Pemerhatian menunjukkan lapisan IMC pada ENIG lebih nipis dan kecil berbanding ENImAg. Ketebalan IMC untuk kedua-dua permukaan secara beransur meningkat dengan masa penuaan. Berdasarkan analisis kadar kakisan, SAC/ENIG adalah lebih baik daripada SAC/ENImAg. Walau bagaimanapun, kedua-dua kemasan boleh diterima kerana bacaan kadar kakisan tidak melebihi kadar kakisan 0.1 mm/tahun. Kajian menemui ENImAg boleh menjadi alternatif kemasan permukaan kepada ENIG.

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LIST OF SYMBOLS AND ABBREVIATIONS

Ag	-	Silver
Au	-	Gold
Cu	-	Copper
E_b	-	Breakdown Potential
E_{corr}	-	Corrosion Potential
EDX	-	Energy Dispersive X-ray
ENEPIG	-	Electroless Nickel/Electroless Palladium/Immersion Gold
ENIG	-	Electroless Nickel/Immersion Gold
ENImAg	-	Electroless Nickel/Immersion Silver
SEM	-	Scanning Electron Microscope
HASL	-	Hot Air Solder Levelling
I/O	-	Input/Output
I_c	-	Critical Current Density
IC	-	Integrated Circuit
I_{corr}	-	Corrosion Current Density
ImAg	-	Immersion Silver
IMC	-	Intermetallic Compound
ImSn	-	Immersion Tin
I_p	-	Passivation Current Density
JEDEC	-	Joint Electron Device Engineering Council
KOH	-	Potassium hydroxide
NaCl	-	Sodium hydroxide
Ni	-	Nickel
OM	-	Optical Microscope
Pb	-	Lead
PCB	-	Printed Circuit Board
SAC305	-	Sn-3.0Ag-0.5Cu
SAC307	-	Sn-3.0Ag-0.7Cu

Sn	-	Tin
Zn	-	Zinc
TAB	-	Tape automated bonding
HPDL	-	High-power diode lasers

CHAPTER 1

INTRODUCTION

1.1 Background Study

The electronic packaging industry has been overgrown every year. There are many innovative devices and technologies designed to help people. Communication devices such as cell phones, tablets, televisions, and computers are the main reason for the increasing production of print circuit boards (PCB). Besides, electronic packaging is the fastest-growing sector in the world and growing because of the high production of electronic devices. The high technology for PCB, which can easily connect to the component and achieve excellent performance, has many improvements, mostly in electronic assembly, and has significantly affected the quality of soldering material (La Dou, 2006).

Solder joint quality performance is a very critical issue. The quality of the solder joint in the electronic package, an integrated circuit chip, can be determined as the electronic system's core (Cai *et al*., 2017). It is very important system to control because typically sensitive to electrical, physical, and chemical reactions. High performance and excellent reliability are in the highest demand in the electronic industry. It also gives packaging engineers good knowledge and expertise in existing and emerging integrated circuit packaging technologies. The solder joint must last long to ensure the electronic product can be used more extensively (Schubert *et al*., 2003). The higher performance of the electronic product can be achieved by making the solder joint more reliable. Solder joint reliability is characterized as the solder joint's ability to hold onto the substrate under certain conditions for a specified period without failure.

In addition, the intermetallic compound (IMC) layer is formed between the surface mounting and soldering layers. This IMC layer increases in thickness during thermal ageing after installation due to the solid-state reaction at the solder joint formation (Xu *et al*., 2005). The formation of a solder joint is important for bonding solders and substrates. Strong knowledge of the metallization of solder substrate reactions is essential for soldering joints because the IMC layer that develops from this reaction is necessary to achieve reliable and robust solder joints. However, the IMC layer's excessive growth may lead to a degradation in the solder's joint reliability (Xue *et al*., 2010; Jiang & Chawla, 2010). Therefore, the IMC layer's growth rate must be controlled during the soldering process. As a result, reliability issues that usually occur at the solder joint formation can be managed and handled.

The evolution of this industry has led researchers to improve this sector, particularly in soldering techniques. The researcher is making improvements to this technology to increase production and also improve quality. PCB production mostly uses wave soldered or reflow soldered, including hand soldering, which is often used for rework. A new and advanced laser soldering technology has recently been applied in the electronic packaging industry. Laser soldering provides significant benefits in electronic packaging compared to reflow soldering because it has unique characteristics, including directed and non-contact heating, fast heating, and a short time process (Han *et al*. 2008).

Besides that, many studies were conducted on the reliability of the joint and interfacial reactions between solder and different surface finishes. The development of new surface finishes is still in slow progress. Electroless nickel/immersion gold surface finishes are the industry's most popular (Bunce *et al*., 2017). Even though electroless nickel/immersion gold (ENIG) is the most commonly used in electronics applications, it also has its disadvantages (Li, 2015).

1.2 Problem Statement

The Restriction of Hazardous Substances (RoHS) legislation has prohibited tin-lead solder use since 2006. In the electronic packaging industry, lead has been prohibited from being used due to environmental issues and health effects. Leaded material has known to be related to health risks. In addition, inhalation of lead particles can harm the human body by affecting the respiratory system and blood circulation. Sn-Ag-Cu (SAC) solder is one of the good alternatives for replacing lead solder composition because of its environmentally friendly material.

In general, PCB has been manufactured by using a wave or reflow soldering process, including hand soldering is still standard practice in electronic assembly. However, a high-temperature tool such as a reflow or wave soldering technique can damage sensitive small electronic components. The heat was conducted at a specific time for the reflow soldering technique, and the cooling rate was low.

When electronic industries have shifted to lead-free compliance, surface finishing requirements have become more crucial for PCBs. Copper is widely used as a substrate due to its excellent conductivity and soldering surface. However, the coated copper substrate is one of the choices due to its corrosion resistance and good effect on the solder joint. Since electroless nickel/ immersion gold (ENIG) was developed as an excellent, outstanding solderable surface finish and highly resistant to corrosion, this surface finish is well recommended in electronic industry applications. However, the ENIG surface finish has its weaknesses and disadvantages. ENIG surface finishing needs a higher cost due to the price of gold metal. It also has a black pad issue that may cause fragmented solder joints due to the gold-plated bath immersion process. This problem has negatively affected ENIG's reputation as an excellent surface finish in the electronics industry.

The study of solder joint behaviour in a corrosive environment are not many reported and investigated. still new in research area. Corrosion is one of the electronic industry damages that can affect the electronic device's performance without realizing it. Research on the reliability of solder joints is severely limited in the corrosion medium. Each electronic device component is exposed to different corrosive environments and chemicals. Today, electronic companies face the reliability issue of solder joint failure due to corrosion in their environmental factors. Many electronic products use an alkaline battery for operation, but leaking alkaline liquid from the battery can harm the devices. The alkaline battery can leak potassium hydroxide liquid (KOH) without notification and direct contact with electronic components. The battery leak happened due to high temperature and self-discharge, which destroyed the battery. Lastly, the battery's age also influences the occurrence of leaking KOH liquid from the battery. Thus, the polarization test is essential to investigate the corrosion rate on the solder joint formation.

1.3 Objectives

1. To characterise and compare the interfacial morphology of Sn-3.0Ag-0.5Cu (SAC305) and Sn-3.0Ag-0.7Cu (SAC307) on ENIG and ENImAg after laser soldering and the isothermal ageing process.
2. To investigate the effect of SAC305 and SAC307 on ENIG and ENImAg to the corrosion behaviour in potassium hydroxide (KOH) solution using potentiodynamic polarization technique.

1.4 Scope of Study

1. Deposition of ENImAg surface finishes on copper substrates using electroless and immersion plating process.
2. ENIG surface finish is ready-made by the manufacturer
3. Two types of lead-free solder alloys are used, which are Sn-3.0Ag-0.5Cu (SAC305) and Sn-3.0Ag-0.7Cu (SAC307).
4. Solder paste size using needle syringe tip 18 gauge, 0.84 mm diameter.
5. Conduct isothermal ageing at 150^{O}C for different ageing duration hours (250, 500, 750, and 1000).
6. Characterization of IMC formed after ageing and polarization test by using an Optical Microscope (OM), Scanning Electron Microscope (SEM), and Energy Dispersive X-ray (EDX).
7. Conduct polarization test using the potentiodynamic polarization technique and use KOH as an alkaline solution.

1.5 Significant of Study

This research may provide fundamental knowledge about the solder composition and an alternative surface finish for electronic packaging industries. This research may also better understand the IMC's joint reliability, and interfacial reaction between the lead-free solder with an alternative ENImAg surface finish developed using an electroless and immersion plating process. Besides that, this work can also offer additional information on the corrosion rate of a solder joint concerning its reliability between surface finishes and their performance for the electronic industry application.

1.6 Sustainability Element

Due to many environmental and health issues, lead-free solder has been used as an alternative to lead solder. Lead-free solder has been considered the best soldering material because non-toxic and safe to use in industry, as followed by the Restriction of Hazardous Substances (RoHS) legislation. Laser soldering has several advantages, such as time-saving, as the soldering process only takes a few seconds and can also minimize electricity usage. Besides, ENImAg is selected as a surface finish compared with ENIG to study their solder joint application performance. As mentioned before, ENImAg surface finish can reduce the material cost due to the price of silver being lower than gold.

1.7 Structure of Thesis

This thesis was organized into five main chapters. The first chapter of this thesis is an introduction to this study. The problem statement, objectives study, and scopes for this research are clearly explained in this chapter. The second chapter covered the literature analysis of previous research, such as the basis of electronic packaging, soldering technique, and IMC formation. For experimental workflow to achieve research objectives, such as laser soldering procedure on ENImAg and ENIG surface finish, polarization test procedure and the material characterization preparation are highlighted in chapter three. Chapter four analyses the experimental results in detail with the significant discussion from the experimental work. Finally, the last chapter summarises the experimental research and recommendation for the future research topic.

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