EFFECT OF ENVIRONMENTAL CONDITION AND NICKEL UNDERLAYER ON WHISKERS FORMATION IN TIN SURFACE FINISH

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Special Dedicated to......

My beloved parents,
Yusof Bin Salleh and Inson Binti A. Latiff

My respectful ex-supervisor,
Prof. Dr. Ali Ourdjini

My siblings,
Siti Farhanee Binti Yusof
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All my friends,
Especially to my special one,
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ABSTRACT

The ban on lead in electronic industry caused manufacturers to search for alternative ways to replace lead without affecting the performance of electronic products. Among lead-free alternative surface finishes, pure tin plating has attracted greater attention as potential candidate to replace hot air solder levelling (HASL) in electronic application. However, tin whiskers were reported to form on tin surface finishes and have caused the failure to electronic components. The study regarding whiskers phenomenon is important especially with the miniaturisation of electronic components in the electronic industry because whiskers from adjacent area may touch each other, causing short circuit. The main objective of this research is to study tin whiskering behaviour of immersion tin plating after being exposed under two different temperatures and relative humidity conditions: normal condition (30^{o}C/60%RH) and severe condition (55^{o}C/85%RH). Tin layer was deposited by using immersion process. The effect of external stress on whiskers growth was investigated by applying indentation at 2N load on tin surface. In addition, a nickel underlayer on copper substrate was deposited by electroless plating prior to tin plating to investigate the effectiveness of nickel underlayer in mitigating whiskers formation. Field emission scanning electron microscopy (FESEM) was used to observe the behaviour of tin whiskers and intermetallic compound (IMCs), Energy dispersive x-ray (EDX) was used to determine chemical composition and image analyser was used to measure coating thickness of tin, nickel and whiskers length based on micrographs obtained from FESEM. The results showed that whiskers have formed on immersion tin surface finish exposed under normal and severe conditions. These whiskers formed in various types including straight, bent, kinked, and spiral with striations along their circumference. The tin whiskers length was directly proportional to the exposure time for both conditions; normal and severe. However, under normal condition exposure, whiskers have grown longer than severe condition due to formation of small and irregular shape of IMCs. Indented area of tin surface showed shorter whiskers formed than non-indented area indicating that the whiskers grow longer at lower external stress concentration. The deposition of nickel underlayer on copper was effective in mitigating whiskers formation as no whiskers were observed under both conditions up to 12 weeks.

ABSTRAK

Larangan penggunaan plumbum dalam industri elektronik menyebabkan pengeluar mencari jalan alternatif untuk menggantikan plumbum tanpa menjejaskan prestasi produk elektronik. Di antara semua alternatif kemasan permukaan tanpa plumbum yang ada, saduran timah tulen telah menarik lebih perhatian sebagai calon yang berpotensi untuk menggantikan pengarasan pateri udara panas (HASL) dalam aplikasi elektronik. Walau bagaimanapun hablur sungut timah dilaporkan telah terbentuk di atas kemasan permukaan timah dan menyebabkan kegagalan komponen elektronik. Kajian terhadap fenomena hablur sungut sangat penting terutama berikutan pengecilan saiz komponen elektronik dalam industri elektronik kerana hablur sungut dari kawasan yang bersebelahan boleh bersentuhan antara satu sama lain menyebabkan litar pintas. Objektif utama penyelidikan ini ialah untuk mengkaji kelakuan pertumbuhan hablur sungut timah oleh saduran timah rendaman selepas terdedah kepada dua suhu dan nisbi kelembapan yang berlainan: keadaan normal (30^{o}C/60%RH) dan keadaan teruk (55^{o}C/85%RH). Lapisan timah dihasilkan melalui kaedah rendaman. Kesan tegasan luaran ke atas pertumbuhun hablur sungut diselidik dengan mengenakan daya lekukan 2N ke atas permukaan timah. Selain itu, satu lapisan bawah nikel di atas permukaan kuprum dimendapkan menggunakan kaedah saduran tanpa elektrod sebelum penyaduran timah dilakukan untuk menyiasat keberkesanan lapisan bawah nikel terhadap pengurangan pembentukan hablur sungut. Mikroskopi medan pancaran pengimbasan elektron (FESEM) digunakan untuk memerhatikan kelakuan hablur sungut timah dan sebatian antara logam, analisis penyerakan tenaga sinar-X (EDX) digunakan untuk menentukan komposisi kimia, dan penganalisis imej digunakan untuk mengukur ketebalan lapisan timah, nikel dan panjang hablur sungut berdasarkan gambar yang diperoleh daripada FESEM. Keputusan menunjukkan hablur sungut terbentuk di atas kemasan permukaan rendaman timah selepas terdedah kepada keadaan normal dan teruk. Hablur sungut terbentuk dalam pelbagai jenis seperti lurus, bengkok, berpintal, dan berpusing serta terdapat jaluran di sepanjang permukaan hablur sungut. Panjang hablur sungut berkadar terus dengan masa yang didedahkan untuk kedua-dua keadaan; normal dan teruk. Walau bagaimanapun, di bawah pendedahan keadaan normal, hablur sungut telah tumbuh dengan lebih panjang berbanding keadaan teruk berpunca daripada pembentukan sebatian antara logam yang kecil berbentuk tidak sekata. Kawasan lekukan di atas permukaan timah menunjukkan pembentukan hablur sungut lebih pendek berbanding kawasan tiada lekukan menandakan hablur sungut tumbuh lebih panjang pada kawasan yang rendah tumpuan tegasan luaran. Pemendapan lapisan bawah nikel di atas kuprum adalah berkesan bagi menghalang pembentukan hablur sungut kerana hablur sungut tidak terbentuk pada kedua-dua keadaan sehingga 12 minggu.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Lead is a well-known material used extensively in electronic components for several decades due to its superior performance and chemical properties. However, due to environmental concerns, lead has been banned in electronics industry because its toxicity is harmful to human health. When ingested or inhaled, lead may cause damage to the brain and nerves which controls the body system. Thus manufacturers of printed circuit board (PCB) have been urged to use lead-free (Pb free) soldering in their products. The European Union RoHS (Restriction of Hazardous Substances) has setup the new laws where starting from 1st July 2006, certain products placed on the market must not contain certain restricted substances in excess of the allowable amount; such as maximum concentration for lead and its compounds is 0.1% by weight [1, 2]. Besides leads, mercury, hexavalent chromium, cadmium, polybrominated biphenyls (PBBs), and polybrominated diphenyl ethers (PBDEs) are also categorised as RoHS - restricted substances as they are toxic too. Banning lead has generated a great amount of changes in the electronics industry, and opened the way for the conversion to lead-containing surface finishes to lead-free alternatives.

Surface finish is the most important part in PCB fabrication and is defined as a layer on top of the bare copper surface. There are several surface finish metallurgies commonly used in the electronics industry including hot air soldered levelled (HASL), organic solderable preservatives (OSP), electroless nickel/ immersion gold (ENIG), electroless nickel/ electroless palladium/ immersion gold (ENEPIG), immersion silver (IAg), and immersion tin (ISn) [3]. HASL has been the most widely used as surface finish over the past years [4]. However, HASL involves fusing the Sn-Pb onto the substrate with lead as the major component [5]. Since the move towards lead-free soldering, pure tin plating has become the choice for lead-free surface finish [6, 7] because it offers good solderability and is inexpensive.

However, replacement of Sn-Pb by lead-free with tin base surface finishes has the challenging issue and potential problem of tin whiskers formation which can cause serious failure to electronic components and presents reliability issues for electronic components. The conductivity of tin whiskers leads to short circuit if they come into contact [8-10]. Tin whiskers were revealed as early as the 1950s by Bell Laboratories on pure tin plating by K. G. Compton *et al.*[11, 12]. Brusse *et al.*[13] in their paper reported many cases documented according to National Aeronautic and Space Administration (NASA) regarding whiskers failures in various applications from 1946 to 2005. Whiskers are usually found on electronic components such as diode, transistor, and capacitor which have tin finishes. Whisker failures were reported in various applications such as nuclear power plant, military aircraft, communication, and automotive fields which involved using electronic components with tin finishes but have led to electrical failure. In 2005, tin whiskers caused nuclear reactor shutdown at Millstone power station due to false pressure drop reading in a computer circuit card and after inspection was done, a bulk of tin whiskers touching each other were found on the computer circuit card surface which led to electrical shortage due to the conductivity of tin whiskers [14]. Recently, in 2009, a customer of a Toyota vehicle reported that the car was totally undriveable due to damage of the pedal assembly [15]. After investigation was made on the accelerator pedal position sensors (APP) assembly it was found that a number of whiskers have grown on the tin finish of the APP boards causing electrical short circuit and led to total failure of the electronic system [16].

Tin whisker formation is due to multifactorial factors including environmental temperature, residual stress, mechanical force, intermetallic compound (IMC) formation, and the oxidized layer. Gedney *et al.*[17] claims IMCs growth at the grain boundary would generate compressive stress and accelerate tin whiskers growth. Most researchers reported that common types of IMCs namely Cu_6Sn_5 and Cu_3Sn which form within the tin layer and copper base material caused additional compressive stresses to the tin layer; thus in order to relieve the stress, tin whiskers formed [5, 17-19]. Chen *et al.*[5] in his research stated that an intermetallic phase (Cu_6Sn_5) forms as the immersion plating process starts, thus creating growth over time until all of the tin has been diffused into copper to form Cu-Sn alloy. Therefore it is clearly understood that tin whiskers formation originates from the tin layer itself and creates further growth to relieve the stress. The possible mechanisms proposed by researchers for tin whiskers formation and growth are grain boundary diffusion, dislocation, recrystallization, and interface fluid flow [17]. However, the exact mechanism for tin whisker formation is not yet clear until now.

Even though there are literatures on tin whiskers phenomenon, no concrete mechanism and mitigation method have been established yet. This is because multifactorial factors of tin whiskers formation have to be considered such as plating thickness, environmental conditions, external stress, and other factors that would generate the IMC formation. Some mitigation methods proposed by previous researchers such as, underlayer coating, annealing or post baking, reflow, and conformal coating method were used to date to mitigate the whisker growth [20-22]. Besides, addition of alloying elements in Cu lead frame also has potential to mitigate the whiskers formation [23].

1.2 Problem Statement

The fundamentals of whiskers growth have been addressed and most of the basic concepts currently used to describe whiskers growth were proposed. The electronic industry has successfully used Sn-Pb alloys for soldering and surface finishes since 1960's. However, with the move towards lead-free in electronic products, pure tin and tin-based alloys are considered as the most suitable alternatives replacing these Sn-Pb alloys. Thus, tin whiskers phenomenon is again at the forefront and may be considered as a serious reliability concern in the electronic industry especially with the miniaturisation of electronic components. The formation of IMCs namely $Cu_6Sn_{5,}$ is the main factor driving the tin whiskers formation. The IMCs formation generates internal stresses within the tin layer and Cu substrate resulting in whiskers growth out of tin surface which is stress-free.

Among the lead-free surface metallurgies, tin plating has received greater attention in industry owing to its excellent solderability and availability. Electroplating process has been used widely for tin coating in the industry because it is cost effective as compared to the high performance coating coated by physical vapour deposition (PVD) and chemical vapour deposition (CVD). As for soldering process in PCB, the most attractive and simple method is press-fit technology, an advanced solder free fastening technology. Press-fit technology requires a thin tin coating to avoid scraping off and creating a possible conductive particle hazard when the pin is inserted into the PCB. However, in practice, electroplating method is limited by the minimum coating thickness of 7µm. Therefore immersion process is important since it can achieve the thickness of coating as thin as 0.3µm. Many of the previous studies on whiskers growth have focused on electroplated tin and almost none used immersion tin plating.

The main purpose of this research is to investigate and understand the whiskers' behaviour on immersion tin surface finish. This research will focus on the effects of several factors; tin thickness, external stress and environmental condition on tin whisker growth on immersion tin surface finish. In addition, the effectiveness of the nickel underlayer in mitigating the formation and growth of whiskers was studied. The studies were carried out because there are only limited numbers of examples in the literature dealing with the effects of tin plating thickness, external stress applied, and exposure under various temperature and environmental condition for immersion tin surface finish.

1.3 Objectives of the Research

The main objectives of the research are to:

1. Determine the effects of tin plating thickness deposited by immersion process and exposed conditions of different temperature/ relative humidity on tin whiskers.

2. Establish the effect of external stress by indentation on tin whiskers growth for with and without Ni underlayer.

3. Determine the effectiveness of Ni underlayer as mitigation against tin whiskers growth.

1.4 Scopes of the Research

Tin plating was deposited by using immersion process on copper substrates. For the tin whiskers mitigation experiment, a nickel underlayer was deposited prior to the tin plating layer by using electroless plating process.

The plated samples were exposed under different temperature and relative humidity for duration up to 12 weeks. The samples were analysed for tin whiskers growth according to certain time interval to investigate their growth and their length were measured for both with and without nickel underlayer samples exposed under both conditions. The effect of external stress on tin whiskers growth was investigated by subjecting the samples to indentation prior to exposure under the same conditions.

In the characterisation phase, the analysis of tin whiskers and intermetallic compound, IMCs was conducted by using Field Emission Scanning Electron microscopy (FESEM) to investigate the tin whiskers types and IMCs formation within tin layer and copper substrate respectively, i-Solution/ Lite software was used to measure the tin whiskers length based on the FESEM micrograph, and energy dispersive x-ray (EDX) to analyse tin whiskers and IMCs composition. The thickness of tin and nickel coating were measured by using image analyser based on the cross-section samples.

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