Fabrication of SAC107 and Sn-0.7Cu lead free composite solder reinforced with Si3N4 via powder metallurgy route

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LIST OF ABBREVIATIONS

Ag	Silver
Al_2O_3	Alumina
Au	Gold
Bi	Bismuth
Cd	Cadmium
CTE	Coefficient of Thermal Expansion
EDX/EDS	Energy Dispersive X-ray
EPA	Environmental Protection Agency
EU	European Union
HCl	Hydrocloric acid
HNO_3	Nitric acid
IC	Integrated Circuit
IMC	Intermetallic Compound
In	Indium
NEMI	National Electronics Manufacturing Initiative
Ni	Nickel
N	Nitrogen
OM	Optical Microscope
Pb	Lead
PCB	Printed Circuit Board
PM	Powder Metallurgy
RoHS	Restriction of the Use of certain Hazardous Substances in Electrical and Electronic Equipment
SAC	Sn-Ag-Cu
SMT	Surface Mount Technology
TiB_2	Titanium dibromide
WEEE	Waste Electrical and Electronic Equipment
XRD	X-ray Diffraction
ZrO_2	Zirconia

Fabrikasi SAC107 dan Sn-0.7Cu pateri komposit tanpa plumbum diperkukuhkan dengan Si_3N_4 melalui kaedah Metalurgi Serbuk

ABSTRAK

Teknologi komposit adalah pendekatan baharu bertujuan meningkatkan perkhidmatan keupayaan suhu dan kestabilan haba sambungan pateri. Pateri rendah-perak Sn98.3-Ag1.0-Cu0.7 (SAC107) dan Sn99.3-Cu0.7 (Sn-0.7Cu) digunakan sebagai matriks manakala silikon nitrida (Si_3N_4) dengan pecahan berat yang berbeza-beza (0, 0.25, 0.5, 0.75 dan 1.0 wt.%) telah ditambah sebagai partikel tetulang. Pateri komposit disediakan dengan menggunakan kaedah metalurgi serbuk yang terdiri daripada proses pencampuran, pemadatan dan pensinteran melalui gelombang mikro dibantu pensinteran cepat. Pendekatan pensinteran gelombang mikro menyebabkan pemanasan lebih seragam dengan penggunaan kos dan tenaga yang lebih efektif. Projek penyelidikan ini terbahagi kepada dua fasa. Fasa pertama melibatkan fabrikasi dan pencirian sifat elektrik, haba, mikrostruktur dan mekanikal komposit pateri pukal. Fasa kedua adalah kajian mengenai sifat-sifat mikrostruktur, kebolehbasahan dan sifat-sifat mekanikal pengaliran semula pateri / sambungan. Hasil kajian menunjukkan taburan partikel tetulang lebih halus dan sekata menjadikan kekerasan mikro lebih tinggi. Pemerhatian turut mendapati sedikit penurunan takat lebur dan kerintangan elektrik pateri komposit pukal. Prestasi kebolehbasahan pateri komposit telah bertambah baik. Sejajar dengan itu, ketebalan sebatian antara logam (IMC) berkurang semasa proses pematerian. Kesan penguatan serakan meningkatkan kekuatan ricih dan permukaan patah menunjukkan mod patah mulur dengan permukaan kasar berlubang dan bukannya mod patah rapuh pada antara muka (substrak / pateri) sambungan pateri komposit. Secara keseluruhan, penambahan partikel tetulang ke dalam matriks aloi pateri bebas plumbum menunjukan penambahbaikan sifat-sifat yang ada dalam bahan pateri.

Fabrication of SAC107 and Sn-0.7Cu Lead Free Composite Solder Reinforced with Si_3N_4 via Powder Metallurgy Route

ABSTRACT

The composite technology is the new approach to improve the service temperature capabilities and thermal stability of the solder joints. Low-silver Sn98.3-Ag1.0-Cu0.7 (SAC107) and Sn99.3-Cu0.7 (Sn-0.7Cu) solders were used as matrix while silicon nitride (Si_3N_4) with different weight fractions (0, 0.25, 0.5, 0.75 and 1.0 wt. %) were added as reinforcement particles. The solder composites were prepared by using powder metallurgy method consists of mixing, compaction and sintering via microwave assisted rapid sintering. This microwave sintering approach results in more uniform heating with cost-effective and energy efficiency. The research project was divided into two phases. The first phase involves the fabrication and characterization of electrical, thermal, microstructural and mechanical properties of the bulk composite solder. The second phase was the studies on the properties of microstructural, solderability and mechanical properties as-reflowed solder joint/interconnection. It was noted that finer and well-distributed reinforcement precipitates has led to higher microhardness and slightly decreased in melting point and electrical resistivity of bulk composite solder. The wettability performance of composite solder was improved. Correspondingly, the intermetallic compound (IMC) thickness was suppressed during the soldering. The dispersion strengthening effect enhances the shear strength and the fracture surface exhibit the ductile fracture mode with rough dimple surface instead of brittle fracture mode at the interface (substrate/solder) of composite solder joints. Overall, the addition of reinforcements into lead-free solder alloy matrix has improved all the listed properties of the solder materials.

CHAPTER 1

INTRODUCTION

1.1 Background

In microelectronic packaging processes, soldering is a well-known metallurgical interconnecting method. As the interconnecting materials of mechanical and electrical continuity, solder alloys are crucial parts in governing the reliability of high performance packaging of microelectronic (Fulong Zhu, 2007). In the development of package materials system, joint reliability is one of the most critical criteria (Yoon et al., 2009). The solder used is primarily 63Sn - 37Pb, with a melting eutectic temperature of 183°C. To have the ability to structure a metallic bond with copper (Cu) at such a low temperature is the key reason for why Sn-Pb solder joints have been utilized worldwide for so long (Tu, 2007). Lead based solders are widely used in the assembly of the modern electronic circuit.

Despite the advantages of Sn-Pb system, lead (Pb) is a toxic metal and it's conceivably hazardous to ecosystems. Thus, the European directive on the restriction of the utilization of certain hazardous substances in electrical and electronic equipment 2002/95/EC, generally referred to as the Restriction of Hazardous Substances Directive (RoHs) banned the utilization of lead in electronic welds since 2004 (Sivasubramaniam, 2009).

Due to this problem, lead-free based solders are introduced for replacing the lead based solder. Various reliability issues still exist with lead free solder joints. Solder joint reliability depends on upon mechanical strength, hardness and the coefficient of thermal expansion (CTE) that are affected by the microstructure, type and morphology of intermetallic compound (IMC) (Sona & Prabhu, 2013). One approach to improving reliability is by using composite solder, which consists of a solder matrix and reinforcements. Composite solders are known to have good reliability because the reinforcing particles can restrain intermetallic compound formation (Hwang et al., 2012). Studies have been carried out in order to improve and develop methods of constructing composite solder alloys.

Salleh et al. (2011) show an improvement in solderability of the Sn-0.7Cu/Si_3N_4 composite lead-free solder with optimum wettability achieved by 1.0 wt. % Si_3N_4, which reduced the contact angle to 14.25^o. A more rounded and more even thickness of pointed scalloped IMCs presented on the Cu-substrate layer. The IMC phases of Cu_6Sn_5 in composite solders were reduced. Overall, the addition of Si_3N_4 particulates to the Sn–0.7Cu lead-free solder should be higher than 1.0 wt%, as these compositions showed superior mechanical properties Salleh et al. (2012). Chang et al., (2011) reported that presence of titanium dioxide in Sn-Ag-Cu (SAC) solder enhanced the shear strength and was effective in retarding IMC formations. Tsao et al., (2012) studied the influence of titanium dioxide in SC composite significantly improving the shear strength and reliability of solder joints.

Currently, a relatively large number of lead-free solder has been proposed other than examples of the binary systems and ternary systems. Among the most promising lead-free solders, combinations of the SAC family of alloys appears to be more popular due to its modest melting temperature, reasonable solderability, comparable electrical performance and good mechanical properties. Nevertheless, high (3-4 %) Ag content can form large primary Ag_3Sn precipitates, which can deteriorate the ductility of the solder joint. At the present, low (1-2 %) Ag gained more attraction due to its superior performance and lower in cost (Satyanarayana & Prabhu, 2013).

Tin-copper (Sn-Cu) solder is an attractive alternative to SAC alloy due to the solder price. At its eutectic composition of Sn-0.7Cu, this alloy melts at a single melting temperature of 227^{o}C. Sn-0.7Cu solder alloys are the most common solder materials used in the electronics industry due to their better wettability.

However, these solder alloy have poor mechanical properties. Thus, it is the idea to enhance the strength of solder alloy by incorporating with Si_3N_4 as reinforcement. Si_3N_4 is well known for having a good combination of mechanical, thermal and thermos-mechanical properties. It has high strength at high temperatures, good thermal stress resistance with low coefficient thermal expansion and relatively good oxidation resistance comparing with other high-temperature structure materials (Ziegler, Heinrich, & Wötting, 1987).

There are several methods to produce a composite of solder alloys such as mechanical alloying, casting and to date is the method of fabricating composite solder alloy by following the powder metallurgy route. Literature studies have shown that solder properties can be improved by adding ceramic particulates into solder using PM method. Gupta have proved that by adding nano sized Al_2O_3 into the monolithic Sn-0.7Cu solder fabricated via PM technique, the solder mechanical properties were improved (Gupta, 2008).

Clearly, it is now known that the use of reinforced particles to reinforce solders can have a profound impact in giving enhanced properties to the solders alloys used in the electronic packaging industry (Ahmed et al., 2010). This study discusses the influence of Si_3N_4 particles on mechanical properties when they added to solders. Several researches that have been done before by other researchers related to composite solder but none of them have explored on SAC107 and Sn-0.7Cu base solder with Si_3N_4 as reinforcement.

1.2 Problem statements

Currently, Sn98.3-Ag1.0-Cu0.7 (SAC107) and Sn99.3-Cu0.7 (Sn-0.7Cu) solder were widely used as alternative standard due to its great wettability and availability at low cost. However, their properties still lacks in terms of mechanical strength and wettability properties.

The addition of ceramic particles silicon nitride (Si_3N_4) have possibilities in improving the microstructural, physical, thermal, electrical and mechanical properties of monolithic solder. The ideal way to reincorporate ceramic powder particulates into the monolithic solder matrix by utilizing powder metallurgy (PM) routes under a solid state which consist of mixing, compaction and sintering. Generally, finer microstructure distribution enhanced mechanical properties of the ceramic-reinforced composite material.

The thickness of the IMC layer, which indicates the amount of reaction, defined the strength and reliability of the solder joint. Although the formation of the IMC layer is desirable for good wetting and necessary bonding, an excessively thick layer is detrimental to the reliability of solder joints. The problem arises due to the brittle nature of the IMC which makes it prone to mechanical failure even at low loads. A thicker IMC layer would also increase the heterogeneity in the physical properties of material across the joint. Therefore, it is necessary to study on the IMC's formation of SAC107 composite and Sn - 0.7Cu composite.

The effect on the joint strength of solder and fracture surface behavior regarding the shear test were conducted on the joint to analyze the strength between solder of the integrated circuit and printed circuit board. Therefore, the intermetallic compounds (IMC) at the interface given a significant effect on the performances of solder joint strength.

1.3 Objectives

The main purposes of this project are listed below:

i) To study the effect of addition Si_3N_4 particles into Sn-0.7Cu and SAC107 lead free solder on the physical, thermal and electrical properties.

ii) To investigate the influence of Si_3N_4 particles on the microstructure, wettability and solder joint shear performance of Sn-0.7Cu and SAC107 composite solders.

1.4 Work Scopes

The scope of this research is focused on two types of solders namely SAC107 and Sn-0.7Cu reinforced with Si_3N_4 particles. At an initial stage, lead free composite solders were prepared by mechanical dispersing different weight percentages (0, 0.25, 0.5, 0.75, and 1.0 wt. %) at micron- sized SAC107 and Sn-0.7Cu. Next, the solders composite is prepared by using powder metallurgy method in which the step mixing on 200 rpm speed within 1 hour, compaction at a pressure of 4.5 tonnes and sintering at temperature 185^{o}C in 2 minutes.

In order to reach these objectives, the work scope of this study is divided into two phases as described in the following:

Phase 1 – Characterization on bulk composite solder.

The bulk of Sn-0.7Cu – Si_3N_4 and SAC107 - Si_3N_4 composite solder was carried out with the melting temperature, phase analysis, electrical resistivity, coefficient thermal expansion and microhardness test.

Phase 2 – Characterization on composite solder joint.

The composite solder were then reflowed to make a joint between the solder and the Cu-substrate. The composite solder joint have studies the properties on the wettability, shear strength and microstructural analysis which subjected to reliability studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Solder Interconnects in Electronic Packaging

Solders are used as interconnect materials between electronic component and printed circuit board (PCB) through the soldering process by imposing heat above the alloy's melting temperature without melting the metallic parts. Electronic packaging is defined as the bridge that interconnects integrated circuit (IC) and other components into a system-level board to form electronic products. Electronic packaging is typically divided into four levels (Jiang, 2008), as shown in Figure 2.1:

Level 0: semiconductor chip level (integrated circuit (IC)).

Level 1: attachment between an IC die to a chip in a carrier.

Level 2: the packaged IC die mounted to a Copper substrate on the PCB. In the second level the current interconnection technologies used either through-hole or surface mount technologies (SMT).

Level 3: board-to-board interconnects.

Solder has served the interconnecting materials for all three levels of connections (die, package and board assembly) and perform three major functions which is electrical, mechanical, and thermal. The successful functioning of electronic products depends on the reliable interconnections provided by the fast developments of solder joints in the electronic industry.

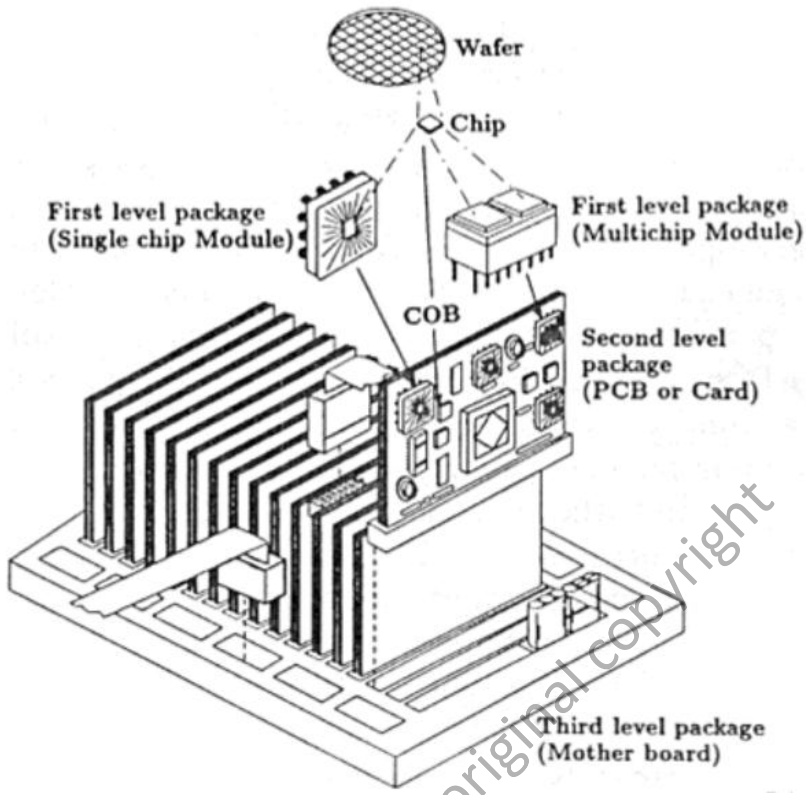

Figure 2.1: Level of electronics packaging (Jiang, 2008)

2.2 Soldering Technologies

Soldering technology plays a crucial role in various levels of electronic packaging, such as solder joints in PCB formed by either surface mount soldering or plated-through-hole (PTH) soldering of components. The development in the electronics industry is toward further minimization, a pin-in-hole or through-hole joint was primarily used in industry and this type of process is still widely used today for machine soldering as well as wave-soldering. With the emergence of surface mount technology (SMT), smaller components and less PCB area are used (Boesenberg, 2011).

Soldering is metallurgical joining method between solder and metallic substrate. In electronic assembly, soldering process is used to connect the electronic components with printed circuit board (PCB). During soldering process, intermetallic compound (IMC) layer is formed at the joint interface resulting from the metallurgical reactions