Peritectic Intermetallic Compound (IMC) Morphology of Transient Liquid Phase Solder – A Short Review

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Abstract. Transient Liquid Phase (TLP) has been a potential bonding technique for high temperature application solder alloy. TLP bonding for solder is a soldering method that using a low and high temperature metal layer for solid form solder, and a mixing of low and high temperature metal powder in flux medium, for paste form solder. Transient Liquid Phase bonding process involved thoroughly consumption of low melting point metal into high melting point metal and results in the formation of high temperature melting point peritectic intermetallic compound (IMC) which enables the solder to be soldered at typical low soldering temperature but, the solder connection can be applied in the high temperature application. The morphology of the peritectic IMCs mainly consist two solids, which is primary α as well as peritectic β together with liquid phase at peritectic temperature. The growth formation of those primary α and peritectic β phases has resulted with a variety of possible peritectic microstructure’s morphology as will be discussed further.

1 Introduction

Peritectic phase formation in solder materials has become researcher’s attention since solder alloy with the peritectic phases has tremendous potential as a candidate for high temperature solder. Since Pb has been banned by Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) directives due to its toxicity, the usage of high-Pb solders for high temperature application has also been restricted. Therefore, the high temperature lead free solder has been introduced. The potential candidates for high temperature lead free solder is Al-based solder, Zn-based solder and Au-based solder alloy [1]. The high-temperature lead-free solders must possess an appropriate melting range for high temperature application. In order to guarantee the efficiency of process flow, the melting range had been well-defined by industries, which is 270 °C to 350 °C [2]. However, the high melting point has been considered as the limitation of these high temperature lead free solder since it has caused higher soldering and processing temperature which could jeopardize the other electronics components in the circuit.

Thus, Transient liquid phase (TLP) soldering technique was introduced and this technique enables a solder joint to be soldered at approximately low temperature but resulted in higher re-melting temperature. This high re-melting temperature has allowed the solders to be applied in high temperature application. The high re-melting temperature is due to the formation of peritectic intermetallic compound (IMCs). These IMCs alloys have been attracted considerable researcher attention due to the fact that it can retain high strength to relatively high temperature [3].

Although the formation and growth of the peritectic phases in other metallic alloys is common, the experimental research work and data on the formation of the peritectic IMCs in solder alloys are still not established. Thus, this paper is mainly focus on the investigation of the formation and growth of peritectic phase in TLP lead free solder connections. The formation of the primary and secondary phase as well as its morphology will be discussed.

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2 Methodology

2.1. Transient Liquid Phase bonding technique for solid form solder alloys

The basic principle of Transient liquid phase (TLP) bonding technique was demonstrated in Figure 1. Before the bonding process, a low melting point metal such as Stanum was sandwiched between two high melting point metals such as Argentum in order to form a sandwich structure. The sandwiched solder alloy then undergoes reflow process to form a solder connection between sandwiched alloy and the substrate. The reflow process took about 15-45 minutes. The duration is depending on the prolong heating at the end of the reflow process. During reflow, the Stanum has totally consumed by the Argentum and the liquid phase developed at the interlayer of TLP solder and substrate and results in the formation of peritectic intermetallic compounds (IMCs). The whole diffusion process between Stanum, Argentum, and the substrate has formed a bonding which usually known as Solid Liquid Interdiffusion bonding (SLID) [2,4].

![Figure 1. The Transient Liquid Phase (TLP) bonding/Solid Liquid Interdiffusion (SLID) bonding](image)

2.2 Transient Liquid Phase bonding technique for solder paste.

Transient liquid soldering technique for solder paste is shown in Figure 2. Low and high temperature metals powder such as Stanum and Argentum, respectively, were mechanically mixed in the solder paste mixer, together with the correct amount of flux. Flux is functioning as the mixing medium for the mixing process. The mixing process usually took about 1-3 hours, depending on the amount of metal powder and flux, type of metal powder, mixing speed and mixing medium. After that the resulted solder paste mixture were reflowed onto a substrate for up to 15-45 minutes for the formation of the required peritectic IMCs. Again, the duration of the soldering process is depending on the heating period at the end of the soldering process. TLP solder connection was then formed. However, the experimental method on TLP solder paste is not been widely discussed as compared to SLID sandwiched method.
3 Results

A schematic diagram for the formation of peritectic phase is shown in Figure 3. The formation of peritectic phase occurs at the peritectic temperature ($T_P$) as in phase diagram; Figure 3 (a). The phase diagram consists of three phases in equilibrium, which is two solid phases together with a liquid phase. By referring to the phase diagram in Figure 3 (a), as the temperature increase, the primary $\alpha$ phase has started to solidify. When the temperature has passed the peritectic temperature $T_P$, the $\alpha$ phase has started to transforms partly to the peritectic $\beta$ phase. However, at the temperature below $T_P$, the alloy still consist of ($\alpha + \beta$) phased at this point. Upon cooling, the $\beta$-phase will consume completely the $\alpha$-phase and has caused the separation of the phase boundary between the ($\alpha + \beta$) and the $\beta$-phase. This solid-solid phase transformation is referred as peritectic transformation. Figure 3 (b) shows the schematic morphology of the resulted peritectic phase.

During solidification, there are few types of possible peritectic phase morphology that would occur due to the nucleation and growth of primary $\alpha$ phase to become a peritectic phase. The reported type of morphology is such as alternating banded microstructures. The alternate of the primary $\alpha$ phase and peritectic phase could end up in different interface morphologies. It is reported that, this alternating banded morphology was formed when $\alpha$, $\beta$ and
liquid phase, which consider as the primary phase, contains more solute than the primary phase. This phenomenon could decrease the solute concentration in the liquid, and caused the interface temperature to rise. Thus, the re-nucleation of primary phase above the peritectic temperature, \( T_p \) would occur. The whole decreasing of solute concentration and the re-nucleation of the primary process can be repeated and lead to the alternating growth of layers of the primary and peritectic phase [7] as shown in Figure 4.

The second type of peritectic morphology was island-like structures and the third reported morphology was simultaneous coupled growth [6]. Figure 4 also shows the island-like schematic morphology. Theoretically, the island-like morphology appears when \( \beta \) nucleates on \( \alpha \) [6]. Meaning, the \( \beta \) phase was surrounded by the primary \( \alpha \) phase. The island-like peritectic microstructure was discovered by Mohd Said et al, in Sn-10Cu solder paste. The primary Cu$_3$Sn was surrounded by the peritectic hexagonal-Cu$_6$Sn$_5$ forming an island-like peritectic IMCs. However, Mohd Said et al only discover one type of peritectic morphology; island like peritectic in their TLP solder alloy [8]. There was a study reported that, if the volume fraction of peritectic phases is small, only island morphology will be observed [6]. Therefore, it is believed that the TLP solder alloy in Mohd Said et al has a small number of peritectic hexagonal-Cu$_6$Sn$_5$ phases compared to primary Cu$_3$Sn phases.

Meanwhile, coupled growth morphology occurs when the two phases, primary \( \alpha \) and peritectic \( \beta \), has grown together parallel to each other, as well as parallel to the growth direction. Or in other word, when alternating banded morphology/ phases grows, it leads to the stable coupled morphology/phase growth as shown in Figure 5.

Interestingly, the compilation of all those three types peritectic phases morphology were observed in Sn-Co alloys, reported by J.M. Liu et al [9]. Sn-Co based alloy is one of the promising candidates for lead free solder alloys [10]. The microstructure consists of primary CoSn layer and peritectic CoSn$_2$ layer as well as eutectic CoSn$_3$ layer. The existence of all those three morphologies is believed due to the equal number of the primary and peritectic phases [6].

![Fig. 4. Schematic diagram of island-like and alternating banding schematic microstructure](image-url)
Fig. 5. Schematic diagram of simultaneous coupled growth microstructure; combination of growth island-like microstructure and growth alternating banding microstructure.

4 Conclusion

The peritectic IMCs microstructure in transient liquid phase lead free solders has been reviewed. The focus was on the morphology of the formed peritectic microstructure which were alternating banded, island-like and couple growth morphology. However, many questions regarding these peritectic IMC is still open for discussion, such as the factor that triggers the transition between these peritectic morphologies.

This work was supported by Ministry of Higher Education Malaysia, under Fundamental Research Grant Scheme (FRGS) FRGS/1/2020/TK0/UNIMAP/02/51.

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