MICROSTRUCTURE OF SOLDER JOINTS AND ISOTHERMAL AGING

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ABSTRACT

This paper deals with some aspects of ternary solder alloy 96.5Sn3Ag0.5Cu (wt.%) – SAC305, in order to determine changes in microstructure of solder joints usually used in electronics realized by Vapour Phase Soldering as well as by accelerated isothermal aging. The samples of solder joints were prepared to evaluate changes in their microstructure due to interfacial reactions on HAL (Hot Air Levelling) and Ni/Au PCB (Printed Circuit Board) surface finishes. Emphasis was placed on studying the effect of behaviour of intermetallic compounds as well as on prediction of reliability of solder joints.

Keywords: *SAC, microstructure, solder joint in electronic, lead free soldering, Vapour Phase Soldering*

1. INTRODUCTION

Predicting reliability of solder joints requires a thorough understanding of solder and PCB surface finishes constitutive behaviour. Studies on SnAgCu (SAC) solder alloys have reported that conditions of aging-time and aging-temperatures can be factors that significantly affect solder joint constitutive behaviour. The results presented in this article are a part of ongoing efforts to construct constitutive models that can predict aging affects on behaviour of SAC solder alloys (solder joints). Temperature and time are typically the key factors that can characterize influence of aging on the joint mechanical behaviour in conjunction with applied mechanical loads, and strain rates that it experiences during use or test conditions. For materials such as SAC solder alloys, time and temperature (apart from applied mechanical loads, test temperatures, and strain rates during test conditions) are factors that significantly alter the microstructure and mechanical behaviour.

In order to understand and improve the mechanical behaviour of solder interconnections it is necessary to investigate microstructural differences caused by the variation of process parameters such as cooling rate (after soldering), and PCB pad (surface finish).

There are indications that soldered structures may be weakened in ways specific to the combination solder, PCB surface finish and soldering process [1-3]. Current proprietary research is showing the above outstanding problems to be associated with the unique characteristics of the interfacial (solder/PCB pad) microstructure evolution of Pb-free soldered joints. With the aims focused on the exploration of the influence of reflow soldering time and isothermal aging temperature on the formation and growth kinetics of IMCs as well as the joint mechanical properties, the present study was performed and the findings on the SAC/Cu interface reported.

The reliability of lead free electronic devices depends strongly on the reliability of the soldered joints while the later one was controlled, mainly, by the formation and growth of the interfacial intermetallic compounds (IMCs) between solder and PCB pad. The morphological features, microstructural evolutions and growth kinetics of the IMCs on the interface of SAC-HASL pad and SAC-Ni/Au pad were investigated. In this work, isothermal aging test results on aged solder joints samples are reported, and aging effects are discussed primarily on aging behaviour and on microstructure.

2. EXPERIMENTAL PROCEDURE

Analysis of solder joint microstructure plays important role in understanding behaviour of final solder joint. Therefore detailed inspection of the microstructure (via light and electron microscopy) explains solder joint mechanical and electrical properties and also influence of consequent thermal ageing process.

As a solder material was used Alpha Metal solder paste OM-350 containing 96.5Sn3Ag0.5Cu alloy. PCB pad was coated with HASL and chemical Ni/Au surface finish. During soldering Au dissolves into solder, therefore Au is not considered later. A ternary solder alloy 96.5Sn3Ag0.5Cu (SAC305) was soldered in form of the solder paste on the pads, by using a Vapour Phase Reflow soldering (VPS) method. The applied peak temperature was 230ºC, time of soldering (including cooling) was 240 seconds. The results of the soldering were sandwich-like solder joints (Fig. 1).

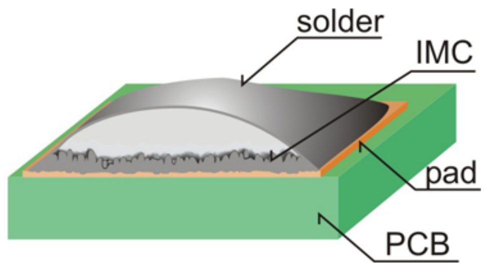

Fig. 1 Cross section of sandwich-like solder joint

In order to study the effects of the reflow time on the formation and growth of the interfacial IMCs, the specimens were reflowed at peak temperature of 230°C for 20s. The pre-heat, dwell and cooling temperature and the time were kept the same for all the solder joints. Melting point of applied SAC305 is in the range of 217°C (solidus) to 220°C (liquidus).

During the isothermal aging experiment, the joints were aged from 0 to 1000 hours at 125°C so as to evaluate the influence of aging temperature and time on the growth kinetics of the IMCs (JESD22-A103C).

For metallographic observation of the interfacial microstructure, the joints were first cross-sectioned perpendicular to the solder-PCB pad interface, polished, then etched slightly by using one portion of 5 % nitric acid HNO_3, 3 portions of – acetic acid CH_3COOH and 5 portions of glycerine $C_3H_5(OH)_3$ solutions. Detailed inspections of the microstructure (via electron and light microscopy) were used with the aim for better understanding behaviour of final solder joint. Electron microscopy was used to define expected composition of single components of the joints (β-Sn, intermetallic compounds).

3. ANALYSIS OF MICROSTRUCTURE OF SOLDER JOINT

SAC alloys are considered one of the most favourable systems as a lead-free solder in industry. Detailed inspection of the joint can answer changes of its properties also as a function of thermal aging process. In SAC305 solder is dominant component tin (β-Sn). Presence of Cu_6Sn_5 phase results from binary diagrams. It is formed mainly at the interface of the solder-Cu pad during the reflow process; the formation of the IMC was dominated by reaction mechanism. As illustrated in Fig. 2, SAC305 samples showed microstructure comprising of β-Sn dendrites, Cu_6Sn_5 phase and the inter-dendritic regions with post-eutectic phases, i.e. β-Sn and Ag_3Sn.

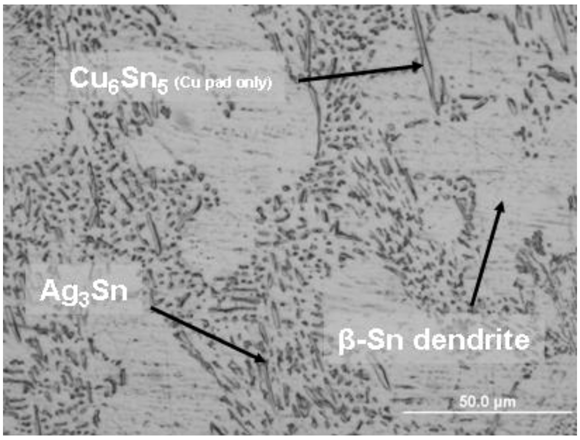

Fig. 2 Microstructure of solder volume after soldering (SAC solder-Cu pad)

In volume of the solder were not such important changes between microstructure of solder immediately after soldering and after the aging (Fig. 3), although some coarsening of needle Ag_3Sn and Cu_6Sn_5 intermetallics can be observed. In interdendritic area is again present Ag_3Sn, in volume of β-Sn dendrites is present Cu_6Sn_5 intermetallic. If soldered on bare Cu pad (HASL), elongated Cu_6Sn_5 can be found in volume of β-Sn dendrites. If soldered on Ni/Au pad, presence of Cu_6Sn_5 in volume of the solder is negligible.

Cu-Sn and Ni-Sn elements form binary intermetallic compounds at the interfaces of pad and solder material during and after soldering (Fig. 4, Fig. 5).

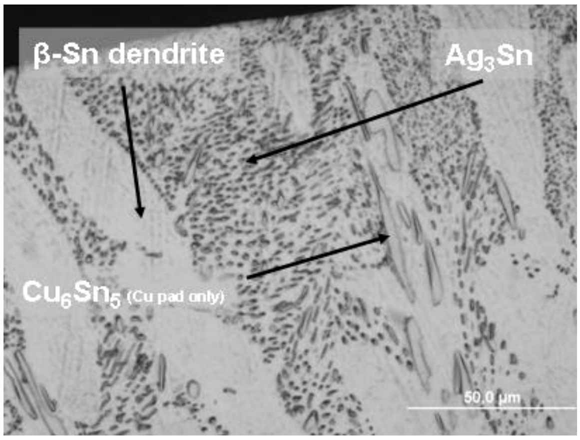

Fig. 3 Microstructure of solder volume after the aging (SAC solder-Cu pad)

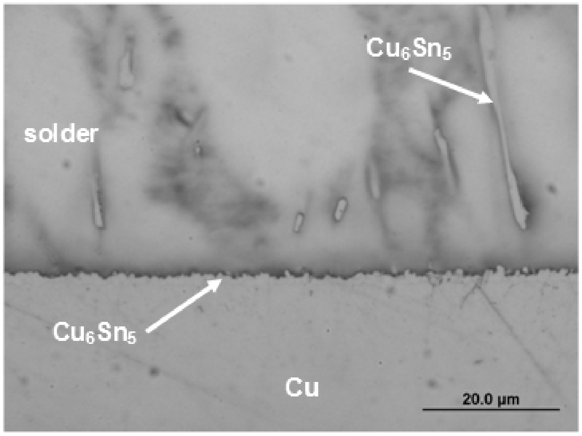

Fig. 4 Interface of SAC305 solder-HASL after soldering

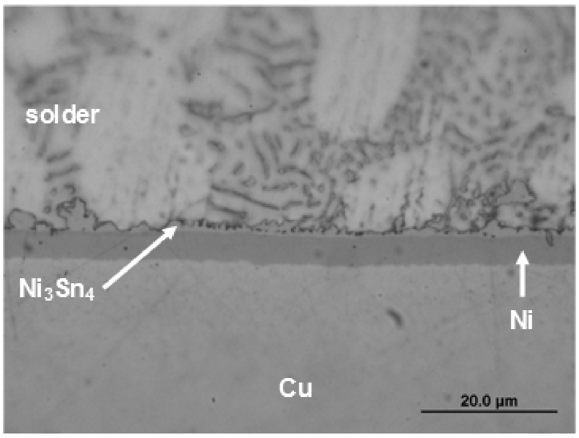

Fig. 5 Interface of SAC305 solder-Ni/Au pad after soldering

It was found that the Cu_6Sn_5 phase was dominant at the interface in as-soldered samples. Cu from the HASL pad extensively diffuses into the molten solder, the diffusion results in formation of Cu_6Sn_5 intermetallic layer at the interface and elongated Cu_6Sn_5 intermetallic in volume of the solder. The intermetallic layer is very rough and irregular. The interface between the pad and solder displays a scalloped-like morphology. The formation of Cu_6Sn_5 intermetallic layer in soldered joint during the reflow process is believed to be originated from the interfacial reactions between its constituting species, Sn from the solder and Cu from the copper pad.

Non-uniform Ni layer (Fig. 5) is well observed at the PCB pad. During the soldering process is between solder and Ni layer formed Ni_3Sn_4 intermetallic.

Comparison of SAC solder-Cu pad interface and SAC solde-Ni/Au pad interface shows some contrast in formed intermetallic layers. Ni_3Sn_4 compared to Cu_6Sn_5 exhibits lower uniformity in thickness (0.8-2.4 μm compared to 0.25-5 μm). It could be caused by plating process of Ni.

The morphologies of the interfacial Cu-Sn intermetallic layers for aging time 500 and 1000 hour are shown in Fig. 6, Fig. 7. The scalloped morphology of the Cu_6Sn_5 intermetallic layer is clearly visible. There was also formed thin layer of Cu_3Sn (approx. 0.25 μm).

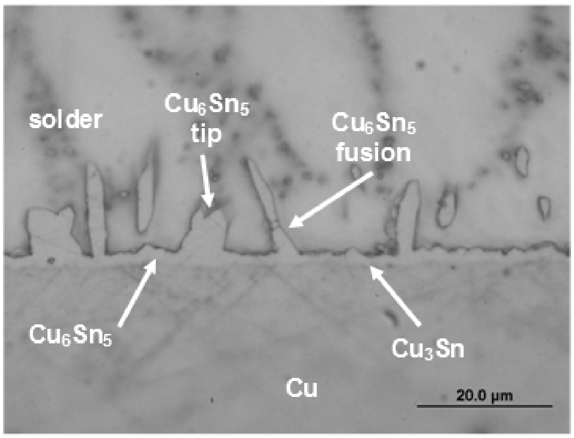

Fig. 6 Interface of solder-HASL pad after 500 hours of the aging

It was noted that the intermetallic layer thickness increases with increasing aging time. The increasing size of the scallops (tips) could be due to some combination of particle agglomeration and ripening according to the literature.

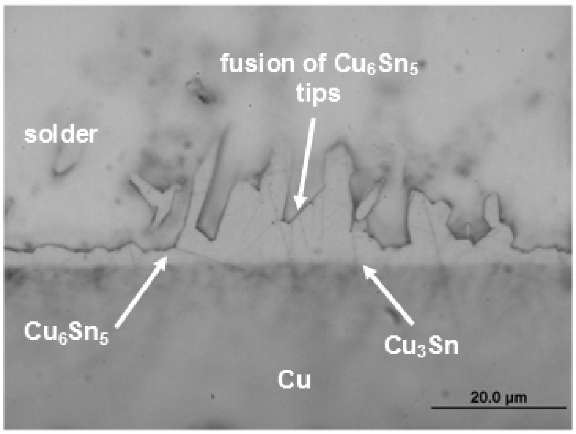

Fig. 7 Interface of solder-HASL pad interface after 1000 hours of the aging

The growth intensity of the IMCs increases also with the increase of the isothermal aging time.

After the ageing (125ºC, 1000 hours) the intermetallic layer fundamentally changed on Cu pad, Cu_6Sn_5 intermetallic layer considerably expanded (2.3-4.3 μm) – Fig. 7, Fig. 8.

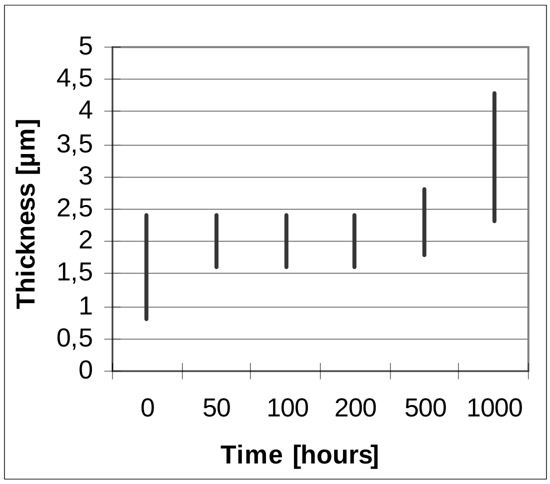

Fig. 8 Thickness of Cu_6Sn_5 vs. time of aging

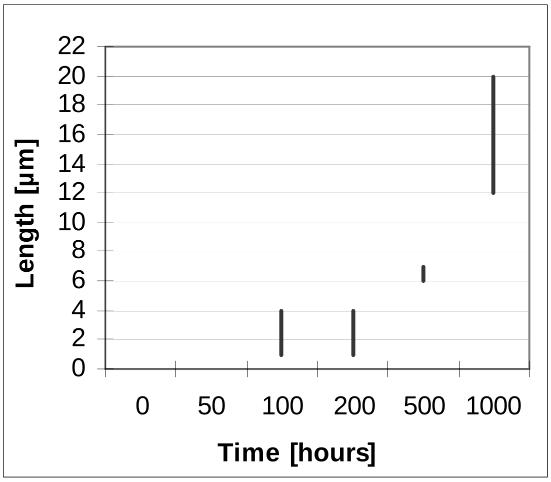

Fig. 9 Length of Cu_6Sn_5 tips vs. time of aging

The most important change was recorded in change of length of Cu_6Sn_5 tips (Fig. 9) – 0 μm vs. 20 μm after 1000 hours of aging.

Solder/ Ni/Au pad interface after soldering as well as after 1000 hours of aging (Fig. 10) exhibits thinner interface intermetallic layer compared with HASL (0.25-5 μm).

The single phases of solder joints (β-Sn, IMCs) were identified via Electron Backscattered Diffraction (EBSD). To mention again, the SAC-Cu and SAC-Ni/Au solder joints were isothermal aged at the temperature 125°C for 1000 hours. The corresponding IMCs growth rate (Fig. 8, Fig. 9) was formulated according to the data from various aging time (0-1000 hours). The growth kinetic of the IMCs was analyzed – it is cause of diffusion principles. It was found that Cu_6Sn_5 was formed at the solder and Cu interface during reflow, but the most important influence on the layer thickness lies in the isothermal aging. With the increase of the aging time, the size of the interfacial Cu_6Sn_5 increased and its morphology was changed from scallop-like to needle-like and then to rod-like.

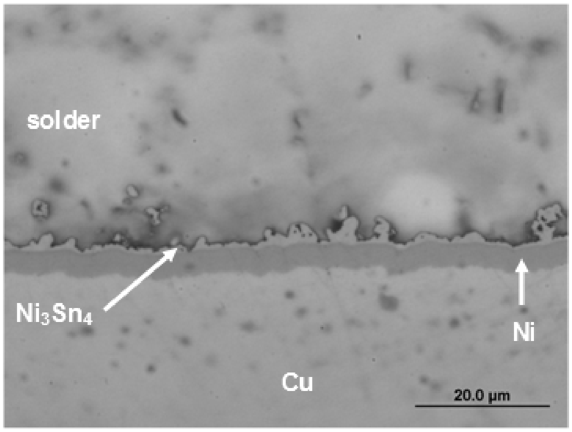

Fig. 10 Solder-Ni/Au pad interface after 1000 hours of the aging

If soldered on Ni/Au pad, non-uniform Ni_3Sn_4 layer is well observed at the pad. During the soldering process is between solder and Ni layer formed non-uniform Ni_3Sn_4 intermetallic. Ni_3Sn_4 intermetallic kept the same thickness also after the ageing (Fig. 10). It is a result of much lower diffusivity of Ni compared to Cu.

4. CONCLUSIONS

The results show that the formation intermetallics and β-Sn dendrites depend on the composition of applied solder and PCB pad. The quality and reliability of microelectronic components and assemblies can be considered as expression of solder joints functionality. These properties are in close connection with the microstructure of the solder joints, which are the result of the soldering process temperature gradient action over the trinomial of solder alloy/paste, electronic components terminals/pin and PCBs pads surface finishes.

Thermal ageing of solder joints proved fundamental change of microstructure of solder joints, significantly influencing properties of solder joints. The most important changes were observed at the interface of SAC305 solder-HASL surface finish (Cu pad).

It was confirmed, that Ni acts as a diffusion barrier for Cu. It prevents migration of Cu atoms from PCB pad to solder.

ACKNOWLEDGMENTS

This work has been supported by foundation of national projects VEGA 1/0298/09 and KEGA 3/6465/08.

This paper was developed with support of the project „Vývoj unikátneho nízko-energetického statického zdroja pre elektrosystémy“, ITMS 26220220029, that is co-financed from Structural Funds EU ERDF within Operational programme Research and Development V-2008/2.2/01-SO-RO and preferred axis 2 Support of Research and Development.

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Received March 13, 2010, accepted July 7, 2010

BIOGRAPHIES

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