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INFLUENCE OF Bi ON THE MICROSTRUCTURE EVOLUTION OF SOLDER JOINTS IN MICROELECTRONICS

Emil LECHOVIČ, Beáta SZEWCZYKOVÁ, Erika HODÚLOVÁ, Koloman ULRICH

Abstract

The aim of this article is study the influence of Bi on the microstructure evolution of lead-free solder joints in microelectronics. The key factors affecting the reliability of electronic products are the interfacial reactions in solder joints, the secondary products of which are brittle intermetallic compounds. Formation and growth of intermetallic compounds are dependent from the chemical composition of solder and base material, from the effects time of the moltent solder on the base material and from the operating temperature. It is very important to mention that these reactions occur not only near the contact of the base material and molten solder in the process of melting and cooling the soldered joint, but they continue even after the solder solidifies.

Key words

soldering, lead-free solder, reliability, intermetallic compound, bismuth

Introduction

The unhealthy effect of lead to the environment and human health has accelerated the research and development of solder in direction of a complete elimination of lead. Besides higher melting temperature and worse wettability (from different temperature profile, different flux...), the lead-free solders differ from the lead containing solders also by different electrical and mechanical properties.

The most of lead-free solder alloys are setup mainly to the addition of a small amount of the third and fourth alloys to the binary alloy in order to enhance their properties. Bismuth is added to the solder alloys in order to decrease the melting point, improve mechanical

Emil Lechovič, MSc. Eng., Beáta Szewczyková, MSc. Eng., Erika Hodúlová, PhD., Koloman Ulrich, Professor, PhD. – Institute of Production Technology, Faculty of Materials Science and Technology in Trnava, Slovak University of Technology Bratislava, ul. J. Botu 25, 917 24 Trnava, Slovak Republic, e-mail: emil.lechovic@stuba.sk, beata.szewczykova@stuba.sk, erika.hodulova@stuba.sk, koloman.ulrich@stuba.sk

properties and increase of creep resistance. Bismuth also enhances the wettability, what can play the role in the use of lower soldering temperature [1, 4].

The alloy systems with the Bi addition are used by the Japanese producers of electronics. They use the alloys with high amount of Sn, mainly SnAgBi and SnAgCuBi.

The typical compositions were tested by the Japanese project NEDO (New Energy and Industrial Technology Development Organization) – SnBi3.0Ag2.0Cu0.5, and later by IMS (Intelligent Manufacturing Systems) project – SnAg3.0Bi2.0Cu0.5. Only a low amount of bismuth content is necessary to reduce melting temperature and achieve better wettability. The addition of higher amount, approximately 5-20% Bi, decreases the melting point to the temperature of eutectic SnPb solders, but good properties of SnAgCu alloy system disappear [6].

The influence of intermetallic compounds on the joint reliability

The most widespread questions regarding lead-free solder reliability is the growth of the intermetallic compounds which are localized on the interface between the solder and substrate. All the known base materials and coatings in electronic together with the active element (Sn) the molten solder form the intermetallic compounds (IMC) on the solder – substrate interface. Their occurrence on the contact area indicates that a good-quality metallurgical joint [2].

Unwanted is mainly the excessive IMC growth, induced by the joint heating in working process (changes of atmosphere temperature or temperature changes due to heat abstraction from the cover) and leading to the growth of IMC to the heavy thickness, and thus the solder – IMC interface becomes a source of cracks formation and spreading.

The growth begins at the room temperature and continues to the area of working temperature of electronics. The growth of layers and cracks brings about the degradation of mechanical and electrical properties which is manifested by the decrease of electrical conductivity of joint. The more cracks in the layer, the higher the transfer resistance, which causes higher heat strain of the joint and further extension of the layer and cracks. This process leads to the joint degradation and gradually to the non-functional joint [3, 7].

The excessive growth also consumes the basic metal and thereby gradually reduces the soldered joint. This may result into the adhesion loss to the substrate which is not wetted by the solder, or into the formation of cracks due to the strain in the intermetallic layer owing to its excessive thickness [3, 5].

Experiments

A four-element alloy SnAgCuBi with a small amount (0.5 and 1.0%) of bismuth was chosen for the experiment. The basic material used was Cu with 99.995 % purity, a frequently used material in electronics. The joints Cu – SnAg1.0Cu0.5Bi0.5 and Cu – SnAg1.0Cu0.5Bi1.0 were formed by hot plate soldering. The soldering temperature was 255 °C through 5 s.

The samples produced were subsequently annealed at 160 ° C for 15 days and were collected from the vacuum furnace at intervals of 1, 3, 7, 11 and 15 days. For observations of IMC (shape and size) present in the structure of solders and at the interface of soldered joints, light optical microscopy was used. To assess the representation of different phases present, the line EDX microanalysis was carried out.

Results

The microstructure of the interface of soldered joint *Cu - SnAg1.0Cu0.5Bi0.5* after the process of soldering followed by heat treatment are shown in Figs. 1a, b, c. After soldering (Fig. 1a), the structure of solders SnAgCuBi0.5 consists predominantly of fine-grained structure. The phases Cu_6Sn_5 and Ag_3Sn which change their shape and size after the heat affecting are dispersed in the volume of solder. These phases are formed from Ag and Cu, which are contained in the composition of solders.

Since the use of soldering materials based on Cu and Sn, formation of IMC Cu_6Su_5 can be observed at the interface of Cu-substrate/solder. The size of IMC layer does not get over 1µm. After annealing, another reaction layer is formed at the interface of substrate and Cu_6Su_5phase documented as Cu_3Sn (Fig. 1b). From Fig. 1b, 1c it is evident that with increasing annealing time the thickness of the IMC at the interface and also increasing while causing significant thickening of solder's structure.

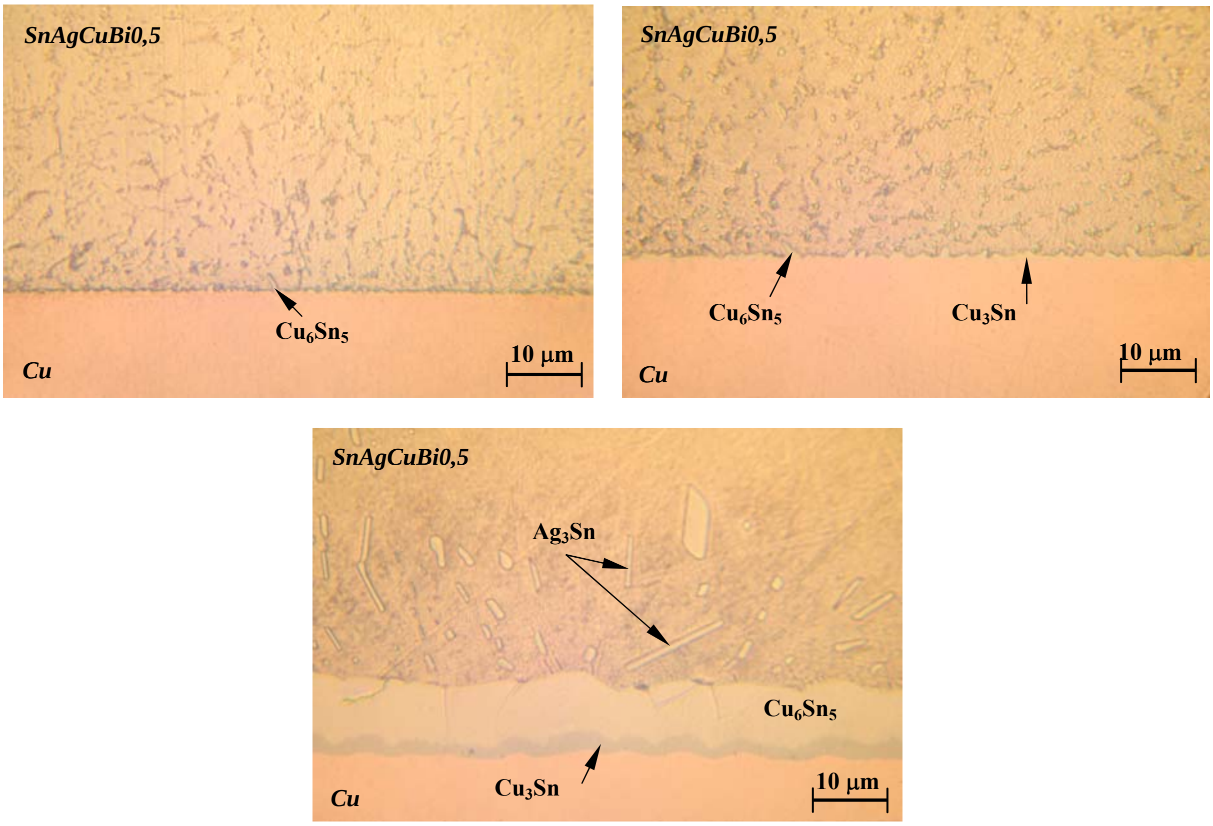

Fig. 1 *Microstructure of the interfacial area of Cu-SnAg1.0Cu0.5Bi0.5 soldered joint*

a) after soldering T = 255 °C, t = 5 s
b) aged at 160 °C for 24 h
c) aged at 160 °C for 360 h

Growth of Cu_3Sn phase can be explained by the fact that the big thickness of Cu_6Sn_5 phase leads to Cu diffusion at the interface, and, due to the lack of Sn, a phase rich in Cu (Cu_3Sn) appears at the interface of the soldered joint. And vice-versa, if Sn phase is located close to the interface, the growth of phase Cu_6Sn_5 is faster and reaches greater thickness due to the reaction of Sn with Cu.

Morphology of the IMC is significantly different. IMC Cu_6Sn_5 is initially characterized by its high inequalities in comparison with laminated Cu_3Sn phase. Over time, however, serrated shape of Cu_6Sn_5 phase takes laminated shape with a unique layered scallop. During the longest time of annealing 360 hrs (Fig. 1c), a relatively continuous layer of the two phases of average thickness of 22 µm was formed. The thickness of the IMC in view of the mechanical properties of the phases can be considered large enough for the joint to be reliable.

In Figs. 2 and 3 of the line EDX microanalysis, the structure of heat affected soldered joint together with the individual increased phases can be observed. The line analysis confirms the presence of Ag_3Sn and Cu_6Sn_5 phases near the interface. Generally, however, larger particles tend to Cu_6Sn_5 phase and smaller particles to Ag_3Sn phase.

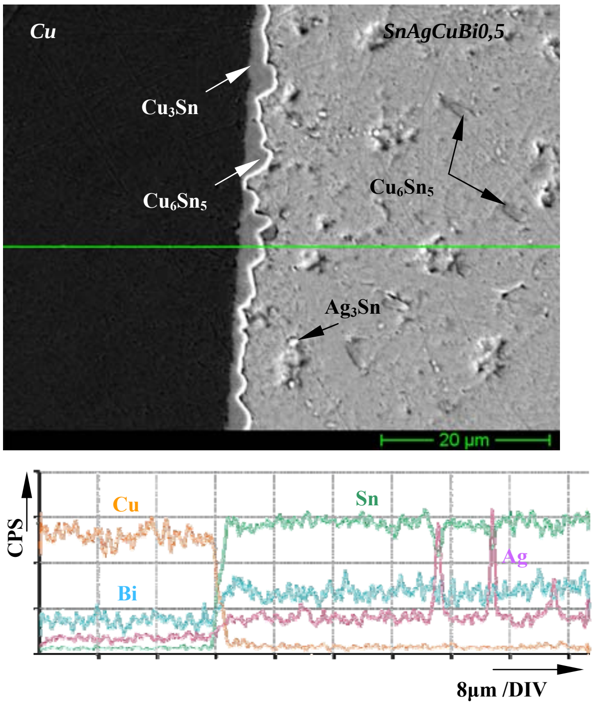

***Fig. 2** Linear EDX microanalysis of Cu – SnAg1.0Cu0.5Bi0.5 solder joint interface aged at 160 °C for 24 h*

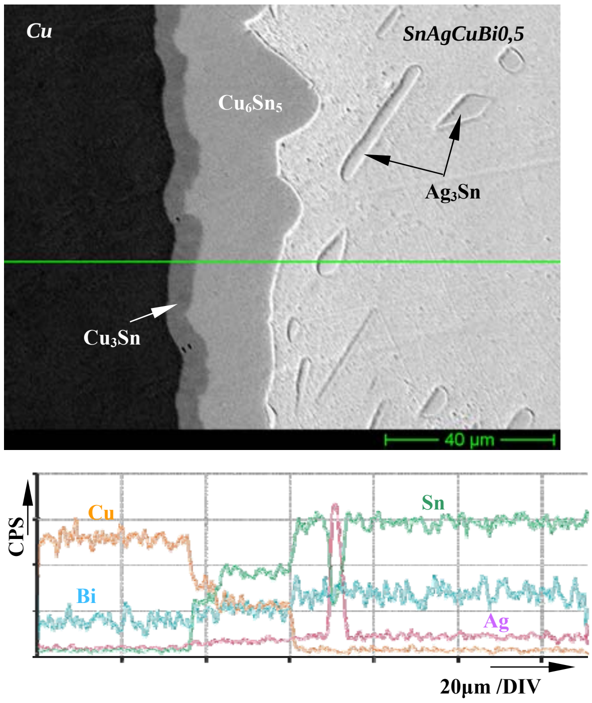

***Fig. 3** Linear EDX microanalysis of Cu – SnAg1.0Cu0.5Bi0.5 solder joint interface aged at 160 °C for 360 h*

Structure of solder *SnAg1.0Cu0.5Bi1.0* after soldering shows granular structure. Apart from scattered Ag_3Sn phase of various shapes and dimensions, the formation of Cu_6Sn_5 in the form of the letter "F" was observed in the volume of solder. During the annealing of solder joints, there is a change in the growth and shape of IMC.

The sequence of formation at the IMC is the same as in SnAnCuBi0.5 solder, i.e. as the first is the formation of Cu_6Sn_5 phase, and up to the heat affected is the formation of the second phase of Cu_3Sn (Fig. 4b, c). Similarly, during the annealing, the surface of IMC Cu_6Sn_5 also smoothens, but more intensively. It changes from serrated shape to scallop one. "Smoothing" is the most intensive after the longest time of annealing (Fig. 4c).

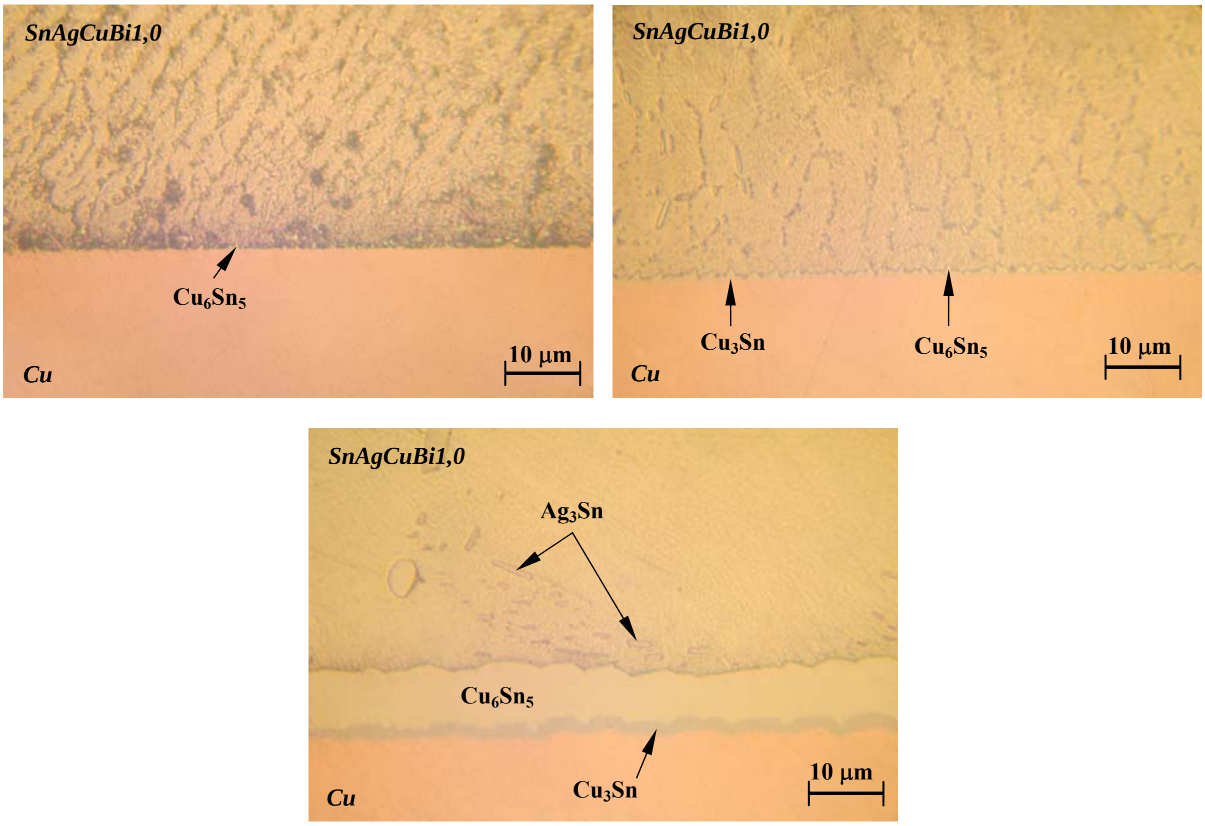

Fig. 4 *Microstructure of the interfacial area of Cu-SnAg1.0Cu0.5Bi1.0 solder joint*

a) after soldering T = 255 °C, t = 5 s

b) aged at 160 °C for 24 h

c) aged at 160 °C for 360 h

When compared with the solder containing less Bi, the thickness of IMC decreased at the interface. SnAgCuBi1.0 solder also varies in the thickness of phases (Ag_3Sn and Cu_6Sn_5) located in the volume and quantity of solders projecting long-scallop skewer (Cu_6Sn_5 phase) of the interface to solders. These changes, microstructure refinement, can be attributed to greater number of particles Bi contained in Sn-rich areas.

The line EDX-microanalysis (Figs. 5 and 6) of Cu - SnAgCuBi1.0 joint confirms the close interface, which is made of Cu_3Sn and Cu_6Sn_5 phases. This was confirmed by the unique occurrence of Ag_3Sn phases in gross IMC Cu6Sn5. As in the solder SnAgCuBi0.5, the presence of Bi precipitates in Sn-rich areas of the EDX microanalysis failed.

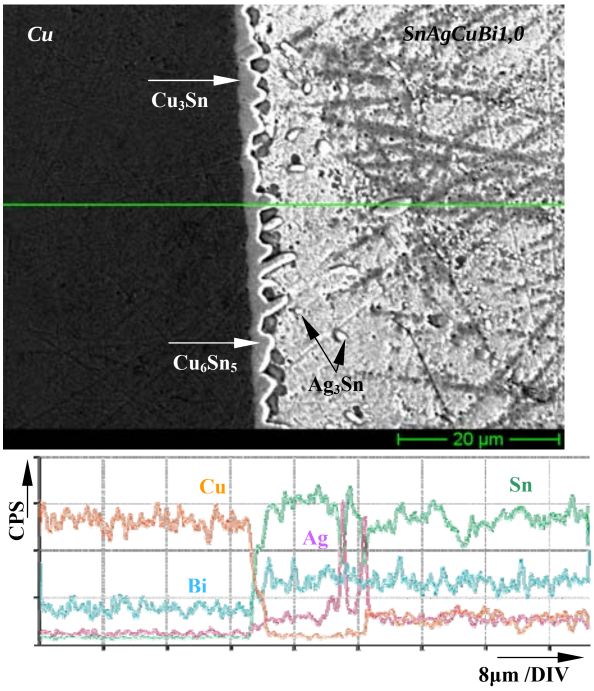

Fig. 5 *Linear EDX microanalysis of Cu – SnAg1.0Cu0.5Bi1.0 solder joint interface aged at 160 °C for 24 h*

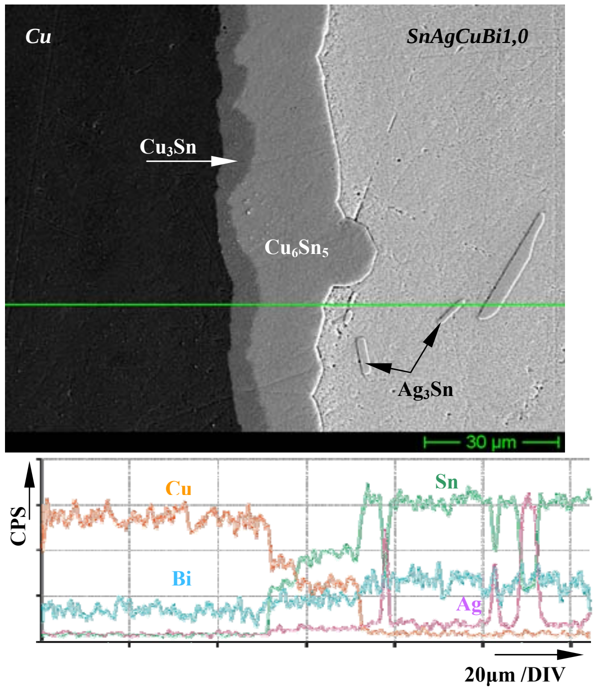

Fig. 6 *Linear EDX microanalysis of Cu – SnAg1.0Cu0.5Bi1.0 solder joint interface aged at 160 °C for 360 h*

Conclusion

From the results of the study of interface the soldering lead-free joints it is clear that, during the annealing (aging) services, there are significant structural changes. Adding 1% Bi to system of SnAgCu alloy leads to refinement of grain size of intermetallic phases in the volume of solders and suppressing the growth layers of intermetallic phases at the interface in soldering joints and thus to the improvement of the reliability of joints. The presence of Bi precipitates owing to the low content (0.5 and 1.0%) of Bi alloys in the systems of SnAgCuBi was confirmed.

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Reviewers:

Pavel Blaškovitš, Professor, PhD. - Department of Welding, Institute of Production Technologies, Faculty of Materials Science and Technology in Trnava, Slovak University of Technology Bratislava

Peter Polák, Assoc. Professor, PhD. – First Welding Company, Inc., Bratislava