SELECTED MICROSTRUCTURAL FEATURES AFFECTING THE SHEAR STRENGTH OF LEAD-FREE SOLDERS/SUBSTRATE COUPLES

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Abstract

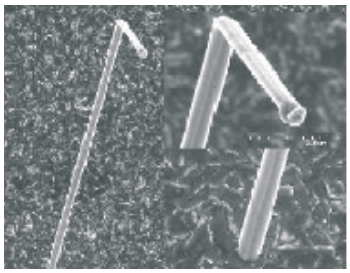
The results of shear strength investigations of the selected lead free-solders/substrate couples are presented. A modified shear test of a half of the lead-free solder/substrate couple has been proposed. A comparative assessment of the solder droplet size effect as well as a composition of intermetallic layer and its morphology are presented. The results achieved provide the explanation of the mechanism of solder droplet size influence on the joint quality. If the lead-free solder droplet is bigger, the time of its solidification is longer, and consequently, the varied droplet structure can be observed. In the case of a bigger droplet size, its microstructure close to the surface, is composed of the crystals orientated in the same direction as the heat transfer. The layer of directionally solidified crystals weakens the joint. A morphology of the selected intermetallic layers was presented as the second problem of couples quality. In comparison to the locally discontinuous layer, the higher shear strength was obtained in the case of continuous intermetallic layer. The paper contains the results of: wettability, microstructure of soldered joints (lead free solder/Cu substrate) and shear tests investigations. The results make possible to formulate the following remarks and conclusions: the lowest shear strength was observed for the joint of pure Sn with Cu substrate, the highest shear strength was observed for the joint of SnBi solder with Cu substrate; practically, two times higher than for pure Sn with Cu substrate and solder SnIn with Cu substrate or solder SnZn with Cu substrate, in the case of double alloys SnZn the lower contact angle results in higher shear strength, however, for remaining investigated alloys such tendency was not observed, the structure of the intermetallic layer on the border of the solder/substrate plays the essential role in the final shear strength of the received joint, the shear strength results characterize the small scatter what indicates the rightness of applied device design as well as correctness of sample preparation and measurement procedure.

Keywords: *transport, recycling, environmental protection*

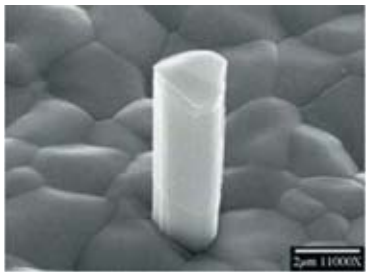
1. Introduction

Nowadays, the intensive interest into materials without lead is observed in different spheres of the industry. A number of lead-free joints increases rapidly in many industrial applications including electronic sets of vehicles, microprocessors and computers. They are produced as the result of join technologies of various materials by means of soldering. The reliability of each element is strongly connected with the level of exploitative properties. Its postulated service reliability is connected with the safety of the vehicle users and all participants of the traffic road, not excepting pedestrian. Hence there is a need to concentrate a special attention on complex material investigations being a base for the process optimization with regard to the results as well as environmental safety. Soldering by means of a soft solder is a typical technology used in practice. Unfortunately, such solders contain the lead and also require the application of fluxes containing the chlorine and fluorine compounds, which are responsible for the environmental pollution. A behaviour of many elements, used in the contemporary electronics and in the electrical engineering strongly depends on the quality of different type of joints, transferring not only the loads (e.g. mechanical and thermal), but also characterizing specified, high requirements with respect to the level of electric conduction (so called electric contacts). This problem is solved up to the sufficient degree by an application of standard solders only. Available publications provide data concerning properties of useful lead-solders produced over the recent years.

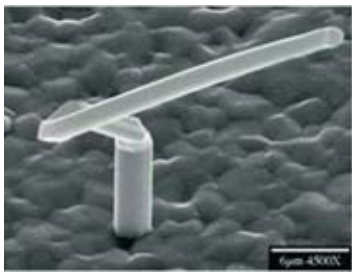
Clech [1], presents the results concerning the properties of alloys on the basis of binary systems Sn-Pb, Sn-Ag and three-componential alloys Sn-Ag-Cu. In general, the majority of lead-free solders show much worse solderability than Sn-Pb eutectic ones, what unfavorably influences on the quality of joints. On the other hand, an improvement of the wettability requires elaboration of the suitable flux [2]. The physicochemical properties of fluxes and lead-free solders were determined by Henderson et al. [2]. The processes proceeding between the binder, flux and materials of subset removals and solder field were investigated in the case of manufacturing of printed-circuitboard. Moreover, they considered the effect of halide activator content in the flux on the kinetics of wettability for different materials used in solder fields of the circuitboards. However, the problem of the proper selection of fluxes creates further objectives to be investigated, for example the visker creation in the case of substrates covered by Sn-alloys. The Sn-viskers may lead to the short-circuit, and as the consequence, decrease a reliability of the joint. A basic mechanism of viskers increase is not fully known as yet, especially in the range of factors affecting their formation rate, however some tests carried out [5] make possible to monitor this phenomenon. These tests take into account two important things: the requirement for isothermal conditions with moisture controlled and cyclic character of the temperature variations. The examples of microstructures presented in Fig. 1 illustrate the visker formation.



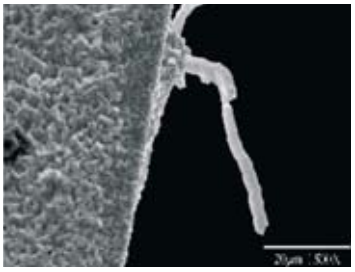
Viskers
M. Williams, NIST
a



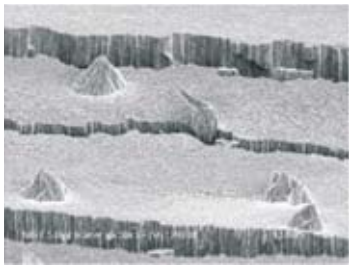
Visker with cross-section
P. Bush, SUNY, Buffalo
b



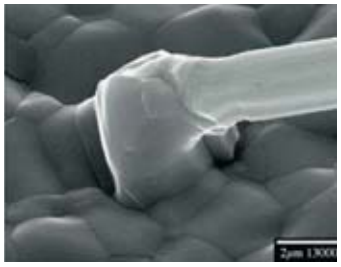
Visker with a loop
P. Bush, SUNY, Buffalo
c



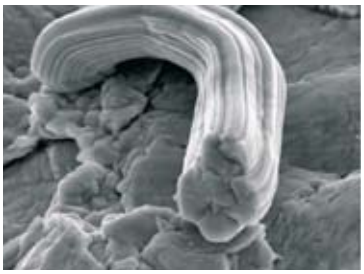
Viskers with a loop increasing from a ball P. Bush, SUNY
d



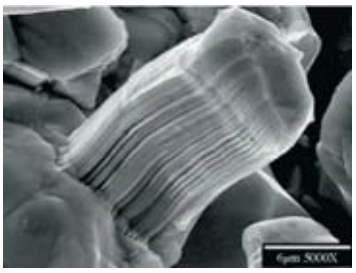
"Knolls" as an initial step of visker formation
M. Williams, NIST
e



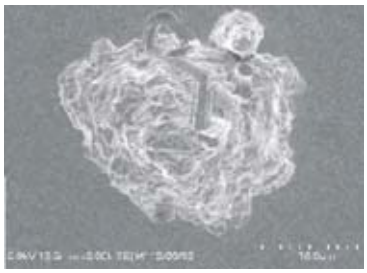
Visker initiation from "knolls"
P. Bush, SUNY, Buffalo
f



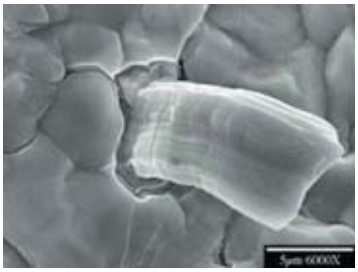
Visker with visible striae
R. Wagner, KEMET
g



Visker with visible striae
P. Bush, SUNY, Buffalo
h



Visker with a loop
i



Visker with rings
P. Bush, SUNY, Buffalo
j

Branched viskers
P. Bush, SUNY, Buffalo
k

Viskers of 14-34 μm length
l

Fig. 1. Examples of the Sn viskers creation on substrate [5]

In the typical lead-free solders containing Ag the quality of joints depends strongly on the Ag_3Sn intermetallic compounds (Fig. 2).

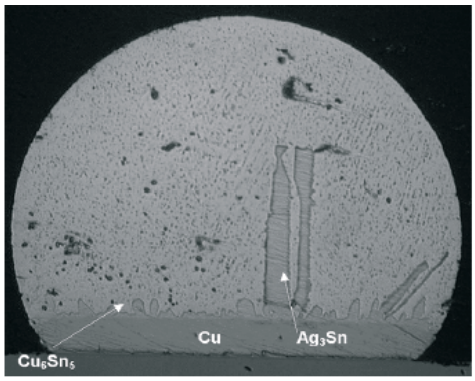


Fig. 2. Microstructure of solder drop on Cu substrate with phase identification [2]

It has been found that the reliability of joints decreases when the Ag_3Sn intermetallic compounds are in a form of large plates, which grow dynamically during slow rate of cooling [2]. If such solder joint will be subjected to the thermo-mechanical loading, its reliability may be reduced significantly.

Appearing cracking mechanism is connected with the state of deformations due to tension. It takes place between the large plates of the Ag_3Sn intermetallic compound and β-Sn matrix. Therefore, from the structural point of view, the most essential is to obtain fine dispersive joint microstructures as a consequence of high cooling rate. Also, it has to be noticed that the additions of the third and fourth components into lead-free solders on the basis of Sn-Ag decrease the melting-point and improve both the wettability and reliability of the solder joints [4].

The paper is limited to the selected couples of lead-free solder/Cu substrate tested in the range of wettability, optical and scanning microscopy and shear strength.

2. Shear strength test

The reliability of the selected material couples was assessed on the basis of shear strength test carried out after the wettability investigations. The wettability tests were carried out in the Foundry Research Institute in Cracow using the following measurement conditions: temperature - 230°C, duration of test - 5 min, flux on colophony basis. The procedure for sample preparation and experimental procedure elaborated by Foundry Research Institute were used in all investigations. The shear strength tests were conducted using the original equipment, elaborated and made in the Motor Transport Institute (Fig. 1). It can be directly installed on the universal INSTRON testing machine.

Fig. 1. Original equipment directly installed on the testing machine INSTRON 8874 for shear strength test

Tab. 1. Shear strength and contact angles of selected couples lead free solder/Cu substrate

Lp.	Solder/substrate	θ [°]	τ_{max} [MPa]
1	Sn/Cu	47 ± 1	18 ± 1
2	SnIn5/Cu	35 ± 1	24 ± 2
3	SnIn10/Cu	37 ± 1	24 ± 2
4	SnIn15/Cu	38 ± 3	21 ± 1
5	SnIn20/Cu	33 ± 1	19 ± 2
6	SnZn4.5/Cu	58 ± 3	23 ± 1
7	SnZn9/Cu	57 ± 3	26 ± 2
8	SnZn13.5/Cu	53 ± 3	28 ± 3
9	SnBi2.5/Cu	51 ± 1	50 ± 1
10	SnBi5/Cu	45 ± 1	49 ± 1
11	SnBi10/Cu	40 ± 1	53 ± 1
12	SnBi15/Cu	37 ± 1	47 ± 1

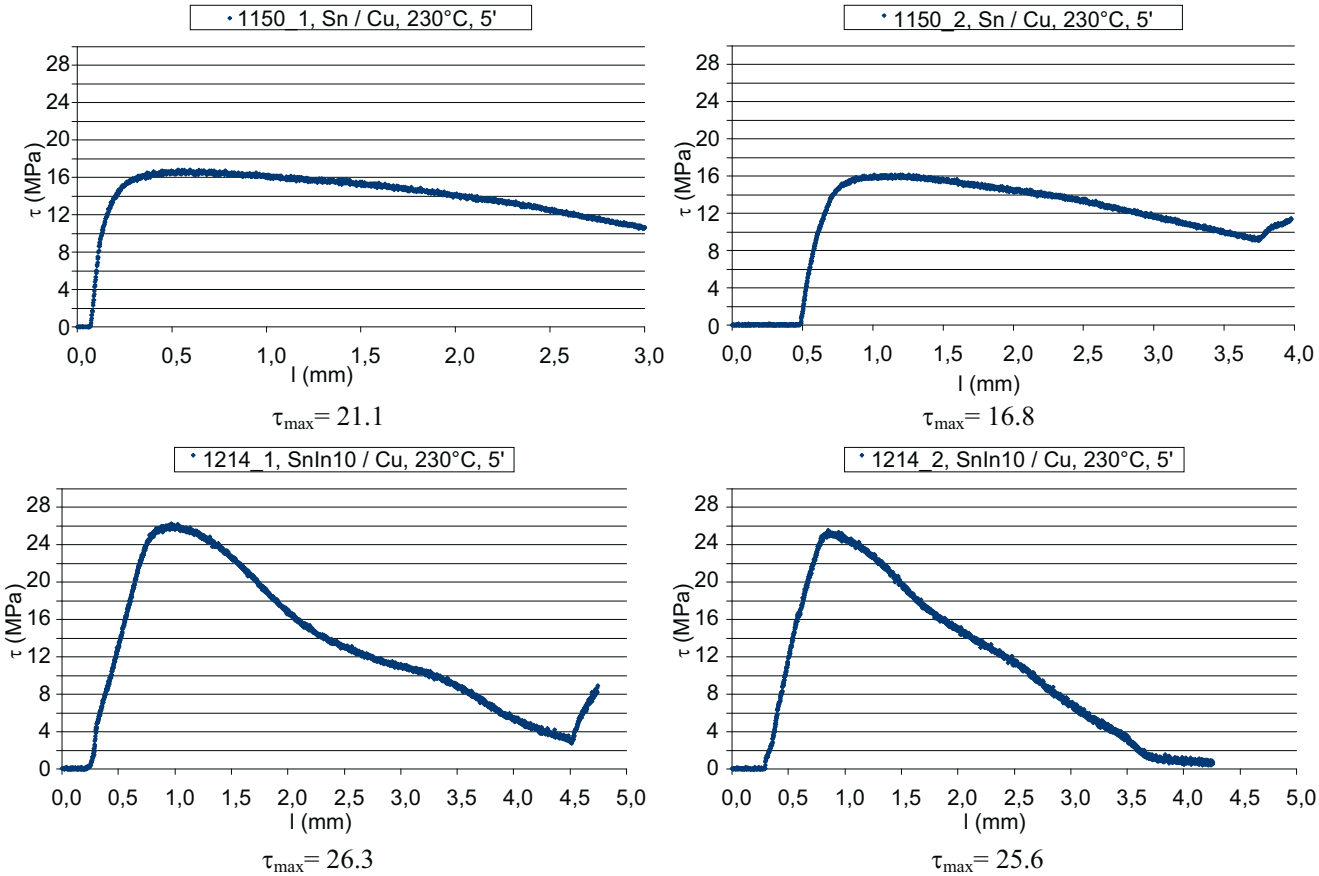


Fig. 2. Example-relationships between the maximum shear stress and a distance from the initial shear surface

The shear strength, was defined as the shear stress (τ) necessary to destroy the couple connection (lead free solder/Cu substrate). The results from all investigations are put together in Tab. 1 (with data including the contact angles) whereas the representative diagrams are shown in Fig. 2.

3. Structural investigations

The microstructural investigations were carried out using optical and SEM microscopy (especially EDS technique). The special attention was given to the identification of the intermetallic compounds formed on the interphase solder/substrate. The intermetallic compounds create less or more compact intermetallic layers of varied morphology and thickness, what may affect the final joint reliability. The microstructures of selected couples solder/substrate with adequate denotations identifying the phases, structural compounds and intermetallic compounds are presented in Fig. 3.

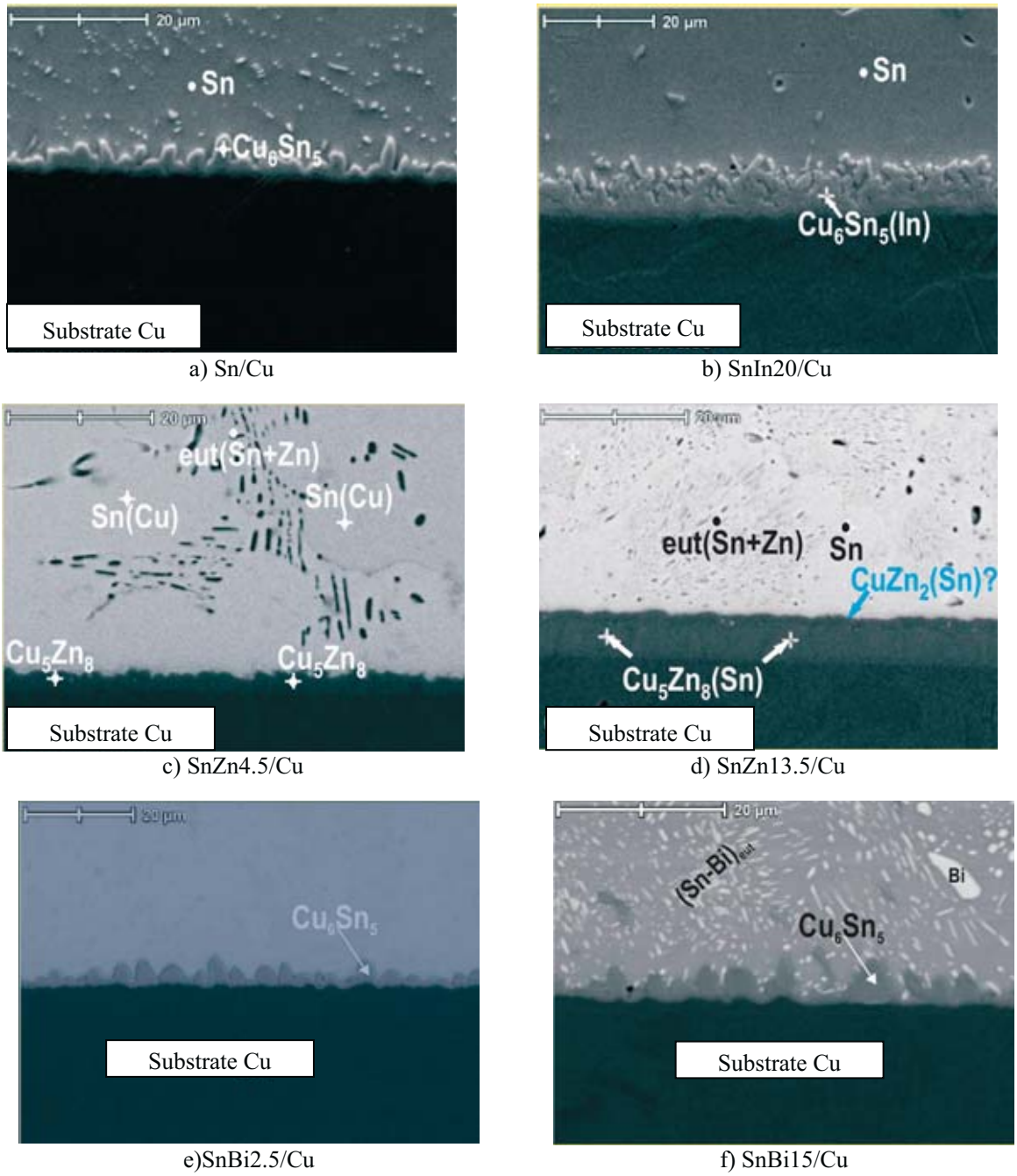


Fig. 3. Microstructures of investigated lead free solder/Cu substrate joints

4. Summary

The paper contains the results of: wettability, microstructure of soldered joints (lead free solder/Cu substrate) and shear tests investigations. The results make possible to formulate the following remarks and conclusions:

- the lowest shear strength was observed for the joint of pure Sn with Cu substrate,
- the highest shear strength was observed for the joint of SnBi solder with Cu substrate; practically, two times higher than for pure Sn with Cu substrate and solder SnIn with Cu substrate or solder SnZn with Cu substrate,
- in the case of double alloys SnZn the lower contact angle results in higher shear strength, however, for remaining investigated alloys such tendency was not observed. Therefore, the systematic investigations should be continued for the confirmation of this feature,
- the structure of the intermetallic layer on the border of the solder/substrate plays the essential role in the final shear strength of the received joint. For example, the joint of the double alloy SnIn20 with Cu substrate shows the lower shear strength than the SnIn5/Cu couple. It is connected with the creation of the Cu_6Sn_5(In) intermetallic layer locally heterogeneous and discontinuous,
- the shear strength results characterize the small scatter what indicates the rightness of applied device design as well as correctness of sample preparation and measurement procedure.

References

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