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Effect of Thermal Stress and Constitution of Lead-Free Soldering Alloys on Creation and Growth of IMC

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Abstract:
This article deals with intermetallic layers which occure at the interface between solder and soldered material. To eliminate hazardous materials, only lead-free alloys, excluding special exemptions, are used today, not only in the Europe Union. Therefore, observing of creation of intermetallic compound between various lead-free soldering alloys and basic material is subject of wide interest. Many factors affect creating of intermetallic compounds, for example soldering temperature, constitution of solder, or setting of technological process of soldering. It depends, for example, on whether the solder joint is soldering by reflow oven, manually, by vapour phase soldering, or by dipping. Research of intermetallic compound growth in context of different soldering process setting, constitution of solder and artificial aging by raising thermal stress are presented in this article. The samples were divided into several groups to make comparison possible. One of these groups was leaved in room atmosphere and that didn't put though any external influence. Tested samples of another groups were thermal stressed in hot-air oven at 150 °C. Another group of samples are presented to make identification of time dependence of intermetallic compound growth possible. Today, electron microscopy is mainly used for analysis of solder joints structure and determination of intermetallic compound layer size. Using this analysis, constitution of individual compounds can be exactly determined. Electron microscopy is not the only way to analyze structure of solder joints. For comparison, analysis of solder joints structure by confocal microscope Olympus LEXT 3000 are presented in this article as well.

INTRODUCTION

The eutectic tin-lead solder is used as a joining material in electronic manufacturing for many years. Tin-lead solders are replaced by lead-free solder alloys due to legislation of European Union and ban of using hazardous substances, which are for example lead, quicksilver or cadmium, in electrical and electronic equipment. On this account, a new lead-free solder alloys are developed. We want to achieve the best possible electrical, mechanical, thermal and chemical properties of the lead-free solder joints, or at least similar properties like solder joints using tin-lead solder. Tin-lead solder have melting point 183°C. The most widely used lead-free solders have melting point in range of 217 – 227°C. Lead-free soldering needs narrow process windows because of higher temperatures about at least 30°C. Tin-copper (SnCu), tin-silver (SnAg) and tin-silver-copper (SAC) are the most often used lead-free solder alloys.

In this study, formation and growth of intermetallic compounds (IMC) between four types of lead-free solders and one tin-lead solder and copper substrate were studied. The IMC growth was examined after isothermal aging at temperature 150°C. Each sample was observed and analyzed using confocal and metallographic microscope. [1][3]

MATERIALS AND EXPERIMENTAL PROCEDURE

Solder alloys and substrate material

For this experiment four lead-free solders and one tin-lead solder were chosen. The lead-free solder alloys are SAC 305 (Sn-3.0wt.%Ag-0.5wt.%Cu), SAC 357 (Sn-3.5wt.%Ag-0.7wt.%Cu) , SAC 387 (Sn-3.8wt.%Ag-0.7wt.%Cu), K100LD (Sn-0.7wt.%Cu). These solder alloys were chosen because of they are often used in electronic industry. The tin-lead solder is SnPb (Sn-37wt.%Pb).

The soldered joints for this experiment were created on copper substrate material. Copper plate was chosen because it is well solderable material, it is often use in electronic industry and it is enough low cost. The substrate material was cut into squares with dimension of 10 x 10 cm. These samples were divided into several groups. The dividing was made according to the time of soldering and the time of isothermal aging. Two groups arose after dividing according to the time of soldering. These groups were divided again so that samples could be aging with different time. Analysed samples were either non-aging or isothermal aging at temperature 150°C for four weeks and eight weeks.

Experimental procedure

The soldered joints were created by hand soldering iron, shown in Fig.1. The soldering temperature was 250°C. The samples differed also in time of soldering. One part of samples was soldering for 10 seconds (creation of soldered joint) and another part of samples was soldering for 60 seconds.

Fig. 1: Hand soldering iron

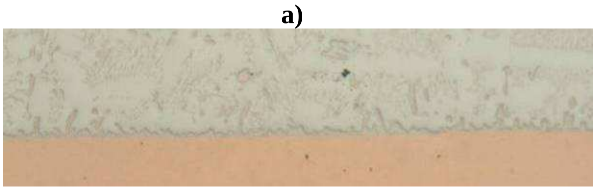
Analysis of samples

The samples were analysed using confocal and metallographic microscope. For analysis, scratch pattern of each sample were made. The photos of structure of soldered joints were made by metallographic microscopes. Hights of IMC in soldered joints were measured by way of confocal microscope.

RESULTS AND DISCUSSION

In Fig.2–10 several scratch pattern of samples with solder joints are shown. The structure of solder joints and the interface of solders and copper is shown in these figures. The IMC well known as Cu_6Sn_5 is formed from Sn in molten solder and Cu of substrate on interface between solder and substrate. The Cu_6Sn_5 IMC grows already at soldering process. The second IMC known as Cu_3Sn grows only during the isothermal aging. It results from analysis of samples and measured values of interface between solder and substrate. The Cu_3Sn IMC grows between Cu_6Sn_5 and substrate. The shape of IMC is not plane but it is scalloped.

a)



b)

Fig. 2: Solder joints - SAC305: a) soldering 10s, b) soldering 60s

a)

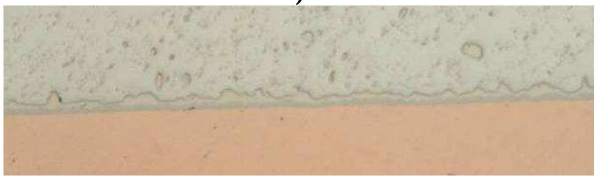


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Fig. 3: Solder joints - SAC305; aging 4 weeks: a) soldering 10s, b) soldering 60s

a)

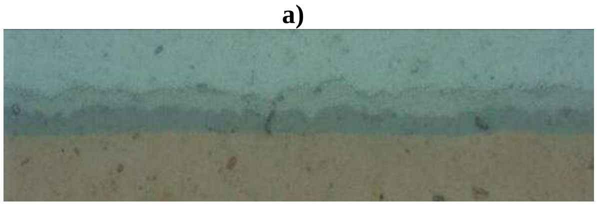

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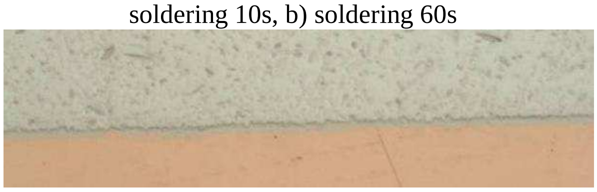
Fig. 4: Solder joints - SAC305; aging 8 weeks: a) soldering 10s, b) soldering 60s



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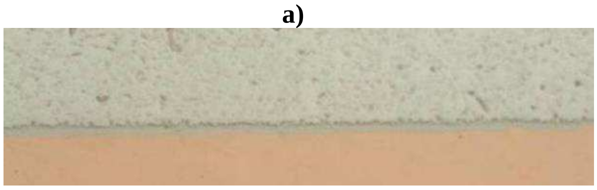

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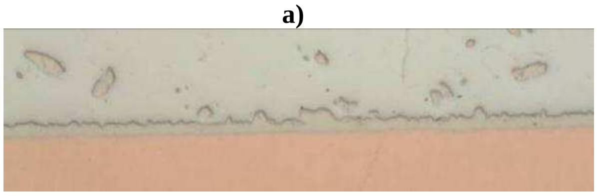
Fig. 5: Solder joints – K100LD: a) soldering 10s, b) soldering 60s

a)



b)

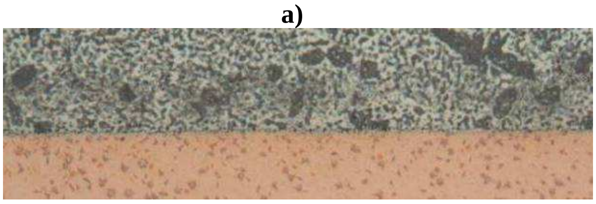
Fig. 6: Solder joints – K100LD; aging 4 weeks: a) soldering 10s, b) soldering 60s

a)

b)

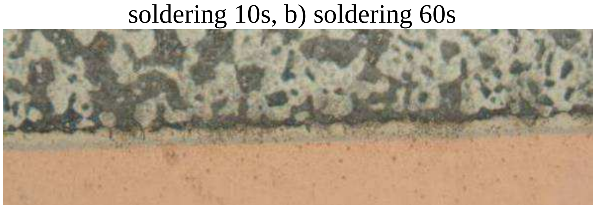
Fig. 7: Solder joints – K100LD; aging 8 weeks: a) soldering 10s, b) soldering 60s

a)



b)

Fig. 8: Solder joints – SnPb; aging 8 weeks: a) soldering 10s, b) soldering 60s



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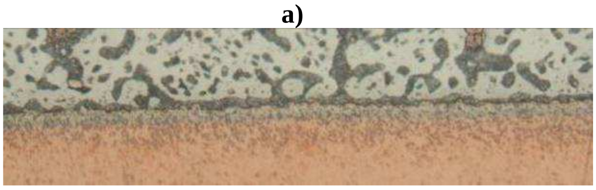
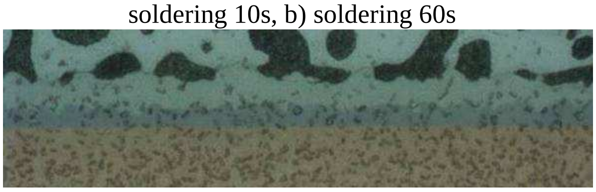


b)

Fig. 9: Solder joints – SnPb; aging 8 weeks: a) soldering 10s, b) soldering 60s



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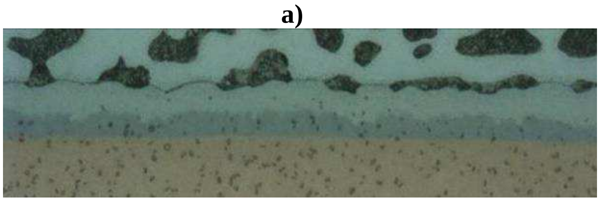
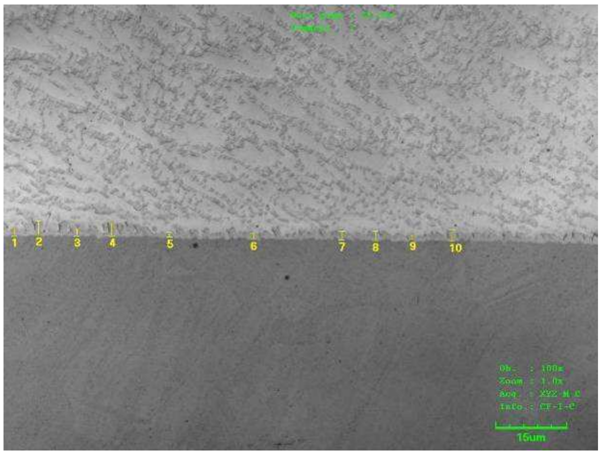


b)

Fig. 10: Solder joints – SnPb; aging 8 weeks: a) soldering 10s, b) soldering 60s

The hights of IMC were measured by confocal microscope Olympus LEXT 3000. The next figures presented several samples and principle of measurement. Twenty values were measured on each sample. Ten values were measured for Cu_6Sn_5 and ten values for both IMC. The hight of IMC is expressed as average of these values. The hight of Cu_3Sn is calculated as hight of both IMC minus hight of Cu_6Sn_5. The measured values are shown in Tab.1. Some samples can not be measured because it was not possible to determine the border of IMC exactly. The measured values from table are graphically present in Fig.14-16.



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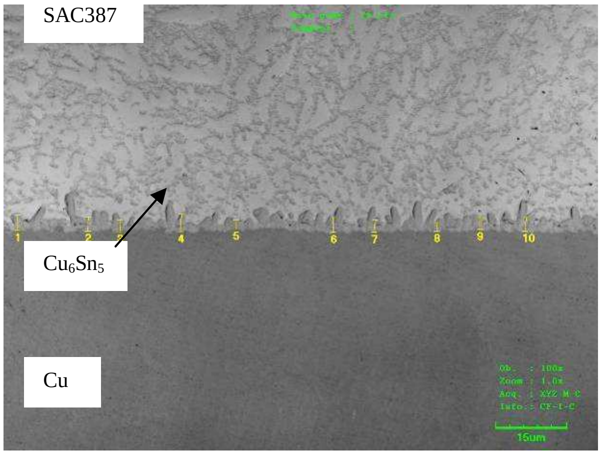

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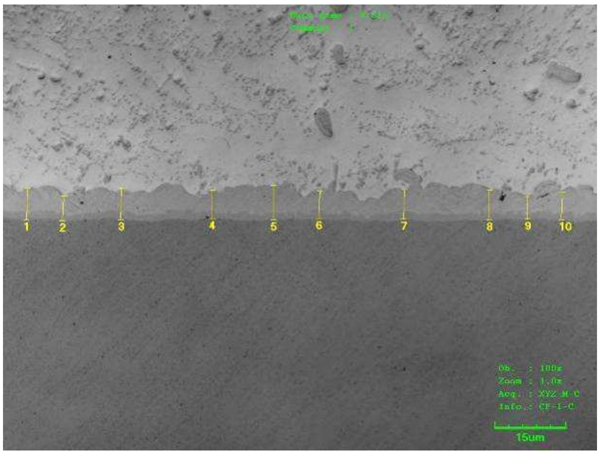
Fig. 11: Solder joints – 387; Cu_6Sn_5: a) soldering 10s, b) soldering 60s



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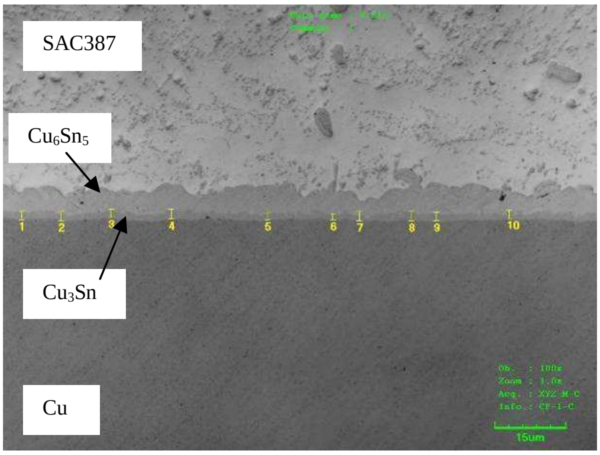

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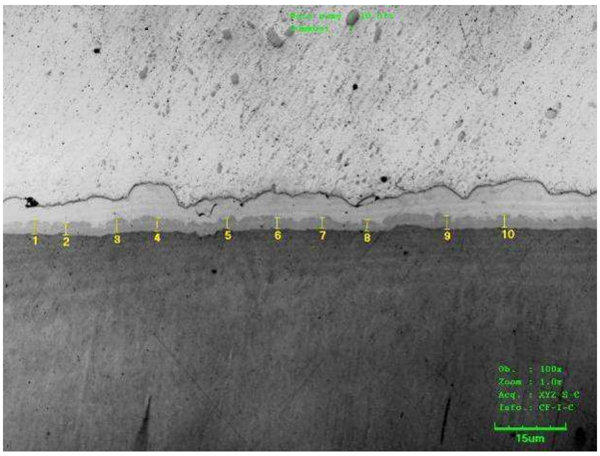
Fig. 12: Solder joints – 305; aging 4 weeks: a) Cu6Sn5, b) Cu6Sn5 + Cu3Sn



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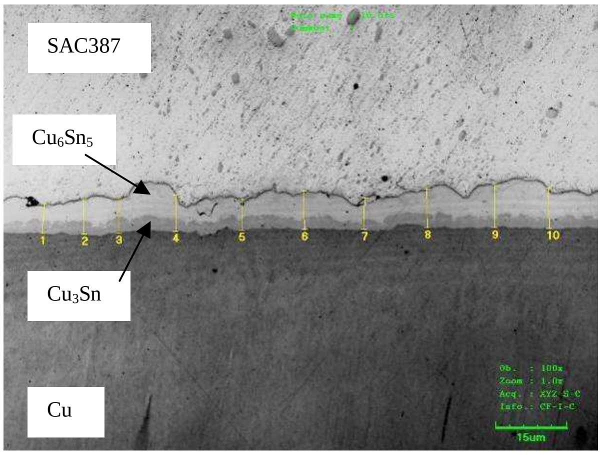

b)

Fig. 13: Solder joints – 387; aging 8 weeks: a) Cu6Sn5, b) Cu6Sn5 + Cu3Sn

Table. 1: Hights of IMC

solder	Cu_6Sn_5 [μm]	Cu_3Sn + Cu_6Sn_5 [μm]	Cu_3Sn [μm]	Cu_6Sn_5 [μm]	Cu_3Sn + Cu_6Sn_5 [μm]	Cu_3Sn [μm]
SAC357_S	1.47	0.00	0.00	2.05	6.45	4.40
SAC357_L	2.24	0.00	0.00	1.80	7.05	5.24
SAC305_S	1.40	0.00	0.00	2.95	6.69	3.74
SAC305_L	2.53	0.00	0.00	3.20	7.64	4.44
SAC387_S	1.85	0.00	0.00	3.59	8.21	4.61
SAC387_L	2.86	0.00	0.00	3.92	8.47	4.55
K100LD_S	3.25	0.00	0.00	3.55	8.38	4.83
K100LD_L	5.65	0.00	0.00	4.03	7.37	3.34
63Sn37Pb_S	0.00	0.00	0.00	4.42	8.02	3.59
63Sn37Pb_L	0.00	0.00	0.00	2.66	7.79	5.13
SAC357_4_S	2.48	6.26	3.78	2.26	6.58	4.32
SAC357_4_L	2.74	6.28	3.54	1.18	8.85	7.66
SAC305_4_S	3.57	6.34	2.77	1.26	8.51	7.25
SAC305_4_L	3.13	6.19	3.06	4.05	9.84	5.80
SAC387_4_S	1.82	6.24	4.42	4.44	9.89	5.46

Fig. 14: Measured values of IMC highs

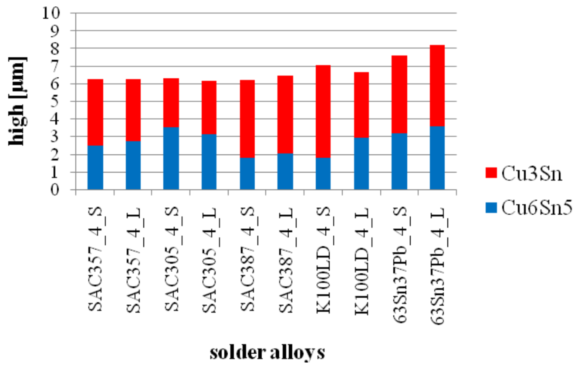

Fig. 15: Measured values of IMC highs

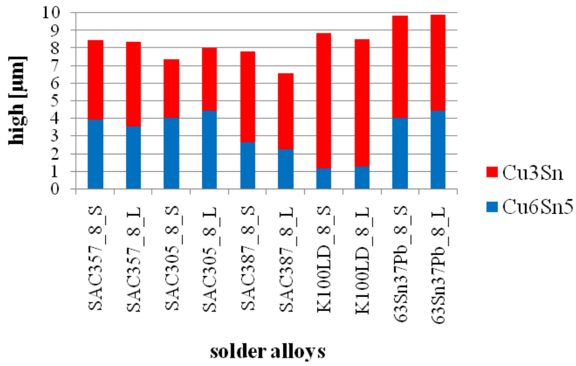

Fig. 16: Measured values of IMC highs

Marking of samples in table means: XXX_0;4;8_S;L. XXX marking type of solder, 0;4;8 present number of weeks for aging and S present short time of soldering(10s) and L present long time of soldering(60s).

CONCLUSIONS

Cu_6Sn_5 is IMC which is created in interface between solder and copper substrate always at soldering process. Cu_3Sn is IMC which is created in interface between Cu_5Sn_6 and copper substrate only during isothermal aging. Longer aging time causes increase of IMC hight. Samples which were soldered for long time have higher hight of IMC. Smallest IMC was formed between SnPb solder and copper substrate. On the other hand, SnPb solder have highest IMC hight of all solders after aging. The hights of IMC are up to 10 µm. SAC solders have very analogous structure of solder joint. K100LD solder which is without silver has different interface in solder joint. Non-aging samples have relatively big hights of Cu_6Sn_5 but after aging these samples have relatively small hights of Cu_6Sn_5 and big hights of Cu_3Sn.

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