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THE INFLUENCE OF SOLDERING CONDITIONS ON CONDUCTIVITY, STRUCTURE AND STRENGTH OF Cu/Sn96Ag4 SOLDERS

WPŁYW WARUNKÓW LUTOWANIA NA PRZEWODNOŚĆ, STRUKTURĘ ORAZ WYTRZYMAŁOŚĆ POŁĄCZEŃ Cu/Sn96Ag4

In the paper the electrical properties of the Cu/Sn96Ag4 solders were studied. The studied solders were produced at 200, 220 and 250°C and within time range 3 to 90 s. Soldering temperatures were chosen to assure the best soldering conditions for the Cu/Sn96Ag4 alloy. The most appropriate temperature of 200°C is the one just above the melting point. The temperature of 250°C is the maximal one recommended by producers, which can be applied for the electronic elements during soldering. The studies have shown that the best electrical properties and tensile strength R_m have samples soldered at times 3 and 30 s, while the highest specific resistance together with the lowest R_m value are observed for samples soldered at the time of 10 s. The soldering temperature have small influence on the strength of the connection/bond however it shows significant affect on the electrical properties.

Keywords: lead-free solders, electrical properties, intermetallic phases

W pracy badano własności elektryczne i mechaniczne połączeń lutowanych Cu/Sn96Ag4. Badane połączenia wykonywano przy temperaturach 200, 220 i 250°C oraz przy czasach lutowania z zakresu od 3 do 90 s. Temperatury lutowania zostały dobrane pod kątem warunków w jakich może być prowadzony proces lutowania przy użyciu stopu Cu/Sn96Ag4. Odpowiednia temperatura 200°C jest tuż powyżej punktu topnienia, a więc najniższa możliwa do zastosowania. Temperatura 250°C jest maksymalną zalecaną przez producentów temperaturą, którą mogą wytrzymać elementy elektroniczne podczas lutowania. Badania wykazały, że najlepsze własności elektryczne oraz wytrzymałość na rozciąganie R_m wykazują próbki lutowane przy czasach 3 i 30 s, natomiast najwyższy opór właściwy połączony z najniższą wartością R_m zaobserwowano dla próbek lutowanych w czasie 10s. Temperatura lutowania ma niewielki wpływ na wytrzymałość połączenia natomiast w istotny sposób wpływa na własności elektryczne.

1. Introduction

A motivation to study the Sn-Ag alloys for soldering applications is EU directive commanding withdrawal of the solders containing toxic metals, especially lead [1]. Alloys that can replace used so far Sn-Pb alloys should be characterized by similar melting temperature and electrical and mechanical properties. Additionally, the alloys should not exhibit structural changes during long-time exposition to high temperatures, that are present inside electronic appliances [1,2].

The mechanical and electrical properties of a variety of lead-free solders are given in the review paper of Abtew *et al.* [3]. Also, some comparison of few lead-free with Sn-Pb soldering alloys is presented in [4]. However, these results are not connected with the structure and soldering time.

The structure of the solder depends mostly on the kind of mutual interaction of the metal and solder, that is from their individual chemical composition and properties. The large influence on the solder have also such factors as: temperature of soldering process, size of the slit between surfaces to be connected, oxidation-protection of the connection, cleanness of the joined surfaces and the type of soldering method [3-9].

The characteristic feature of the soldered connection is presence of the sudden change of the physical and chemical properties (that as consequence influence mechanical properties) on the cross-section of the weld. Also, the intermetallic compounds can be formed at the solder interface due to diffusion at high temperature [10]. A reaction solder-substrate is an exothermic reaction, what causes the intermetallic compounds forming at the

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interfaces have lower energy of formation than metals reacting with each other. The growth kinetics of the phases is proportional to temperature.

The most common intermetallic compound present in the connection of Cu/Sn-based alloys used in electronics is Cu_6Sn_5 [10]. The Pb-free alloys tend to form thicker layers of intermetallic phase at the interface than it had place in case of Pb-based solders. The thickness of the layer is strictly connected to the soldering time and exposition temperature. Therefore, establishing the optimal time-temperature conditions for soldering of each alloy is necessary.

2. Experimental method

Studies were performed on the samples made from Cu 99,999 sheet soldered with Sn96Ag4 paste. The soldering process was conducted at a electrically-heated graphite table placed in a chamber blown with argon gas. Two sheets of copper with dimensions 1,5×20×25 mm were soldered

Two sheets of copper made of Cu 99,999 with dimensions 1,5×20×25 mm were soldered with Sn96Ag4 paste at an electrically-heated graphite table placed in a chamber blown with argon gas. The soldered sheet were cut into smaller samples with dimensions 1,5×4×40 mm. The following soldering temperatures were applied: 200,220 i 250°C, and times of the process: 3, 10, 30, 60, 90 s. As a soldering time, the time of staying at the soldering temperature until it was quenched in water, is considered. The aim of quenching of the samples was preserving the structure obtained during soldering at a given temperature and time. In all samples, the width of the solder/weld was measured. Next, the structural and chemical analyses were performed at scanning electron microscope Hitachi S-3400N.

The electrical properties of the connections were measured with the 4-point method in liquid nitrogen. Each sample was mounted in a special holder, that guaranteed repeatable geometry of the measurement. Two precise voltometers were used, HP 3458A and Agilent 34401A with resolution of 10nV and 100nV, respectively. Thirty separate measurements were conducted on each sample, where the polarization of the current (flowing through the sample) was changed every time. A time interval between single measurements was 2 s.

The mechanical tests were performed at Instron 6633 tensile machine at room temperature; R_m values of the studied samples were determined.

3. Results and discussion

In Figure 1, the structure of the connection made of Sn96Ag4 alloy is presented. The EDS analysis of microregions allowed to identify a phase present at the connection interface as Cu_6Sn_5. It was also proven that no phase containing silver is present at the interface. The presence of silver was detected however in the central part of the solder (Fig. 2), in form of Sn-Ag eutectic.

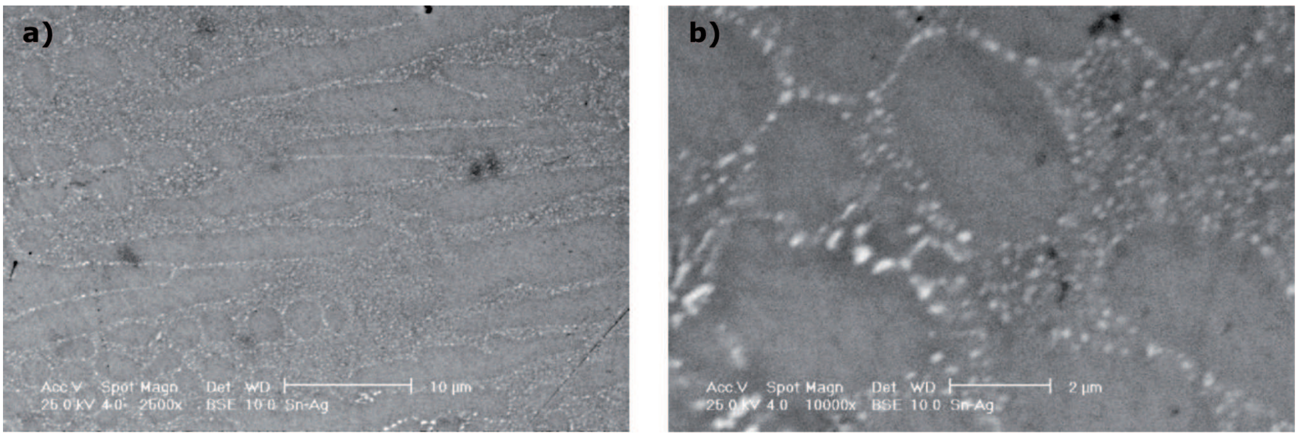

Fig. 1. Structure of Sn96Ag4 connection; a) magnification 2500x, b) magnification 1000x

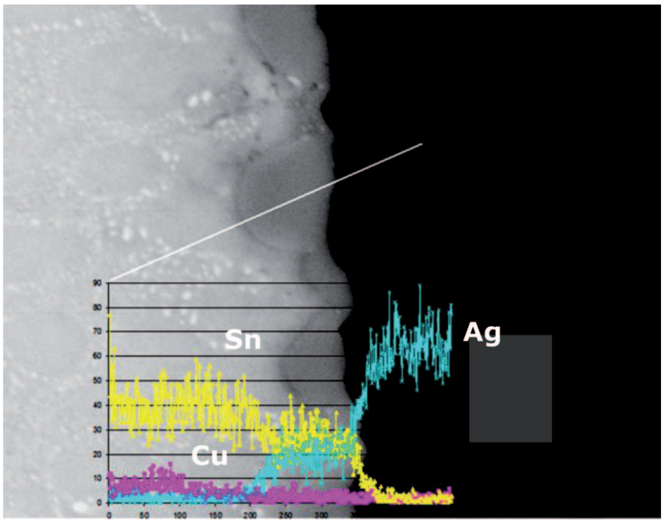

Fig. 2. EDS analysis at interface identifying a phase present there as Cu_6Sn_5

The most important feature of the solders is increase of specific resistance introduced by the connection. The electrical properties of the samples prepared with the soldering alloy Sn96Ag4 at various times and temperatures of the process are presented in Fig. 3. The applied times of soldering are within the range 3-90 s, while only three temperatures were chosen for the studies: 200, 220, 250°C. The obtained results show that the best electric properties exhibit samples soldered at 250°C for 3 and 30 s. Also, the less advantageous time of soldering process regarding the electric properties is 10 s. In case of all samples soldered at that time regardless temperatures, a sudden drop of specific resistance of the connection is observed. The value of specific resistance of the connection made of the lead-free alloy is similar to the one made by the classic soldering alloy.

Figures 4 present the connection interface obtained at the soldering times of 3, 10 and 60 s. A fair layer of intermetallic phase Cu_6Sn_5 is present at the copper/solder interface. Its thickness varies depending on the soldering time from 3 to 7 μm for the samples that underwent soldering process for 3 and 90 s, respectively. Another characteristic feature occurring during increase of the soldering time is change of shape of the interface solder/ Cu_6Sn_5. The evolution is schematically presented in Figure 5, where it is visible that the roughness of the interface changes from rough to smooth one with the soldering time. However, the interface on the lateral side of the connection Cu_6Sn_5/Cu is straight regardless time.

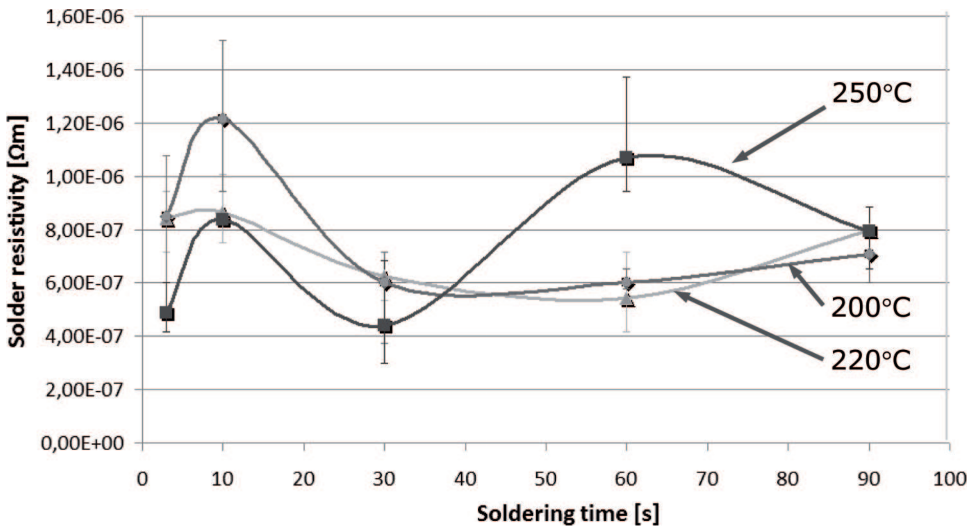

Fig. 3. Influence of time and temperature of soldering on resistivity

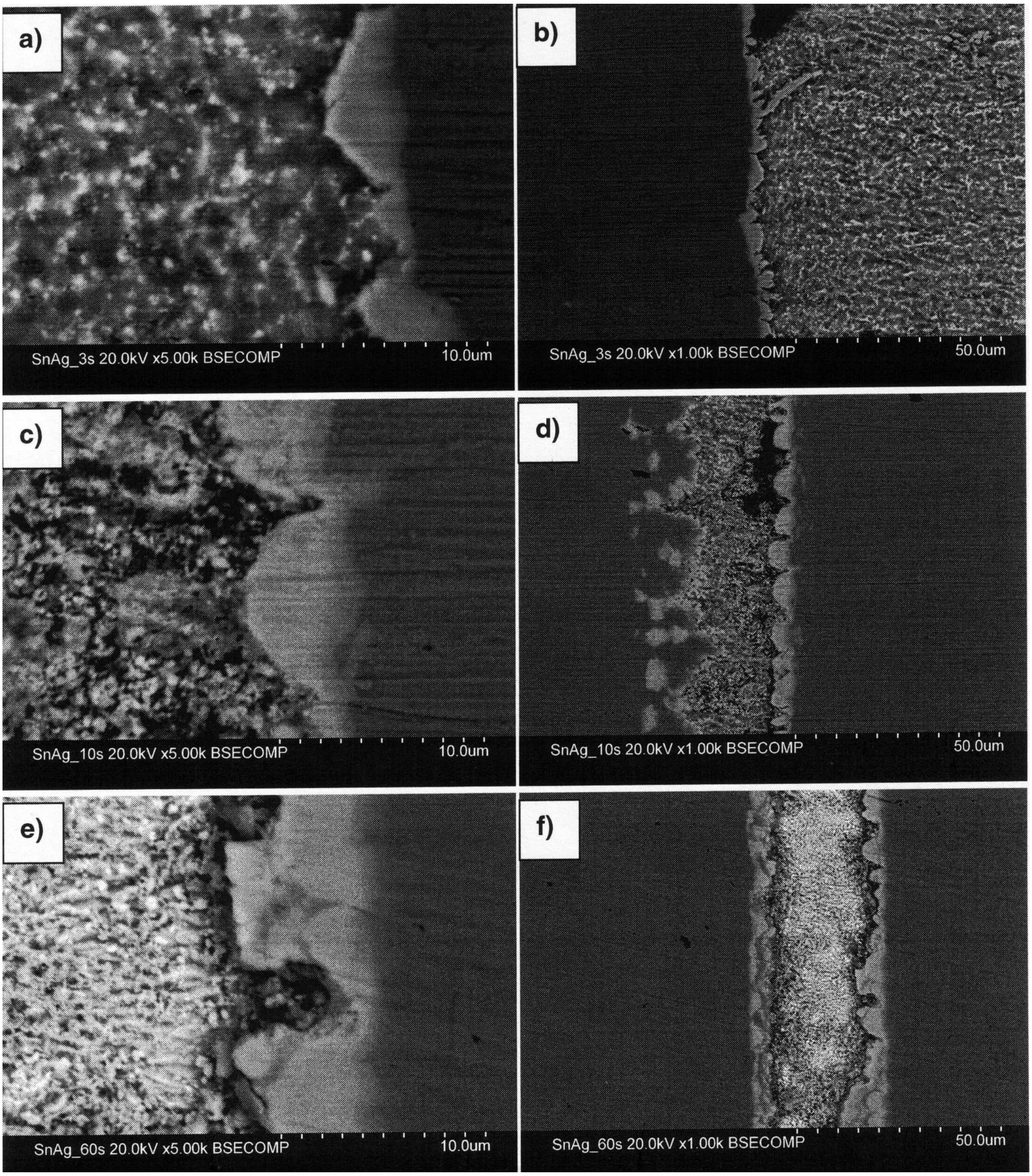

Fig. 4. Connection interface obtained at the soldering times of a,b) 3s, c,d) 10s and e,f) 60 s. The fair layer is intermetallic phase Cu_6Sn_5

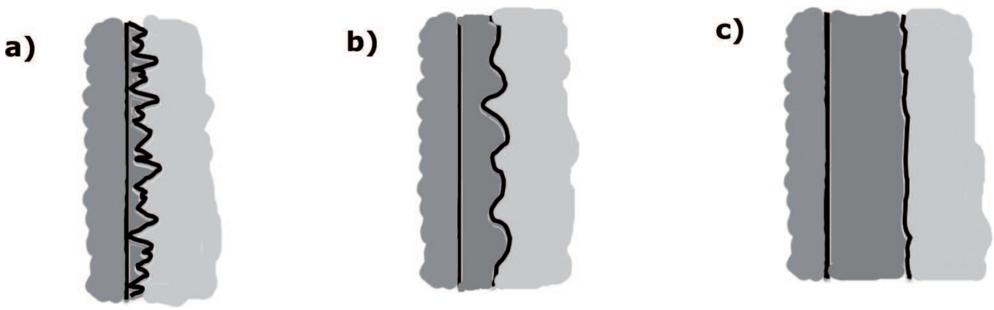

Fig. 5. Schematic representation of evolution of the intermetallic interface within the solder after a) 3 s, b) 10 s, and c) 60 s

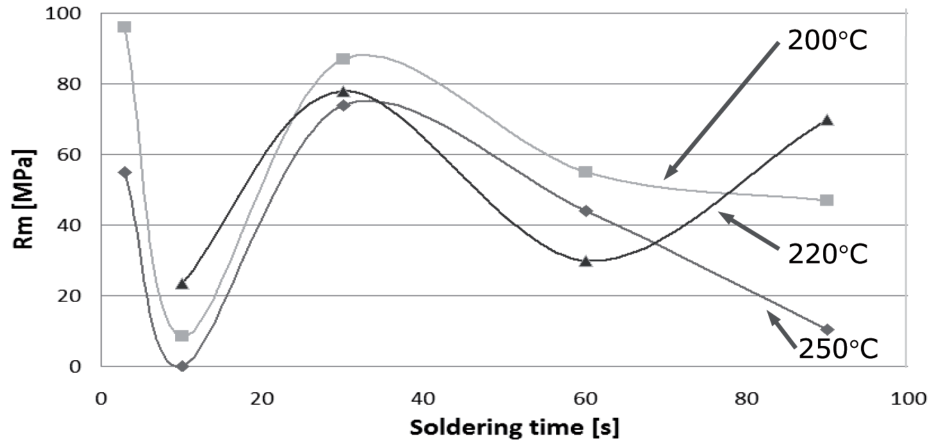

Fig. 6. Influence of soldering time on tensile strength of samples soldered with Sn96Ag4 alloy

The modern soldering alloys should be characterized by good strength/mechanical properties together with good plasticity. Figure 6 presents tensile characteristics of lead-free Sn96Ag4 alloy performed at various temperatures. Couple of factors can influence the mechanical properties of the solder: shape, size and quality of the prepared solder [11] as well as time-temperature conditions.

Three curves in Fig. 6 represent the importance of the applied time to which samples were exposed at the given temperature on the mechanical properties of the solder. Similar to the electrical properties, the samples exhibit the lowest tensile strength at the time of 10 s regardless the temperature. The samples turned out to be so brittle that mounting them on the tensile machine was extremely difficult. In case of the sample 10s/250°C it was impossible to mount the sample, therefore the strength was assumed to be 0 MPa.

4. Summary

The conducted studies showed that one of the most important factors determining properties of a solder are number of intermetallic layers at the interface, their width and character of the interface. The parameters depend strongly on temperature and time of soldering. It was found that the most advantageous time of soldering is 3 s, while the biggest drop of the electrical and mechanical properties was observed at the time of 10 s. The soldering temperature had little influence on the connection.

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