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LEAD-FREE SOLDERS INTENDED FOR HIGHER TEMPERATURES

BEZOLOVNATÉ SPÁJKY PRE VYŠŠIE APLIKAČNÉ TEPLOTY

Abstract

A design for a lead-free solder intended for higher application temperatures. Alternative solder production. Structural analysis, chemical microanalysis, and semi-quantitative chemical analysis of BiAg11 solder. BiAg11 solder wettability on copper, nickel and silver surfaces.

Abstrakt

Návrh bezolovnatej spájky pre vyššie aplikačné teploty. Výroba alternatívnej spájky. Štruktúrna analýza, chemická mikroanalýza a polokvantitatívna chemická analýza spájky BiAg11. Zmáčateľnosť spájky BiAg11 na povrchoch z medi, niklu a striebra

1 INTRODUCTION

Even despite the fact that the European Union's RoHS Directive (on Restriction of Use of Certain Hazardous Substances) relating to the protection of the environment prohibits the use of lead-based materials in the manufacture of electric devices, in some cases it was necessary to obtain an exception from that general requirement, because there had been no adequate replacement in existence by that time. As the above-mentioned EU Directive provides that lead based solders can be used until there is a technically feasible replacement for them, this exception was granted e.g. to solders with high melting temperature containing more than 85 % lead. Typical examples of such solders are the SnPb95 or SnPb90 solders that are used e.g. for stepped soldering with the upper melting temperature of 300 °C.

For the above-mentioned reasons, the paper deals with the search for a permanent replacement for the above-mentioned lead-based solders. Currently, commercially available replacements have certain shortcomings. For instance, the AuSn20 eutectic solder has, on the one hand, a satisfactory soldering temperature, but also – due to the high gold content (80 %) – a very high price. Unlike that, the SnAg25Sb10 eutectic solder (a Motorola patent) is available at a relatively reasonable price, but its melting temperature is too low (only 233 °C).

Therefore, an experimental BiAg11 solder has been developed and tested which might meet the requirements placed upon a satisfactory replacement both in terms of price and melting temperature. The proposed solder does not have an eutectic composition.

2 SOLDER DESIGN, PRODUCTION AND STRUCTURAL ANALYSIS

To select the components to be used for the solder, the following requirements were set:

- Solder components with minimum toxicity,
- Melting range between 260 °C and 450 °C,
- Wettability of the alloy on copper, nickel and silver surfaces,
- Acceptable price.

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Following these requirements, a solder was designed with the composition of BiAg11; this solder substantially meets the predefined requirements.

The wettability on copper, nickel and silver surfaces was subjected to another testing series. Some properties of the solder are shown in the following table (Tab 1).

Tab. 1 Some properties of the proposed BiAg11 solder

Solidus (°C)	262
Liquidus (°C)	360
Density (g.cm^{-3})	9,86
Tensile strength (MPa)	69
Expansion (%)	32

A binary diagram of the Bi – Ag alloy is of a simple eutectic type – see Figure 1. The eutectic reaction L→ (Ag) + (Bi) occurs at the temperature of 262,5 °C. For the designed composition (BiAg11), the melting temperature will be from 262 to 360 °C, which was confirmed by a DSC analysis [6].

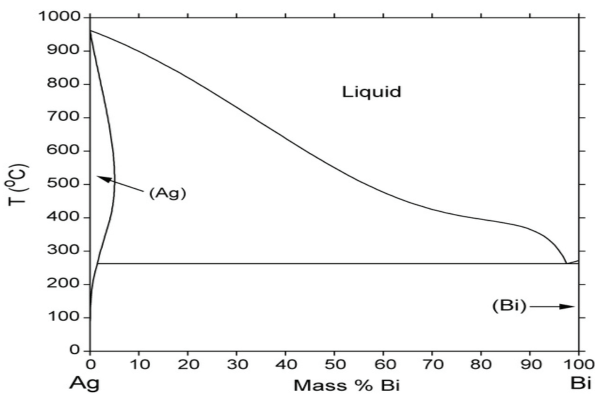
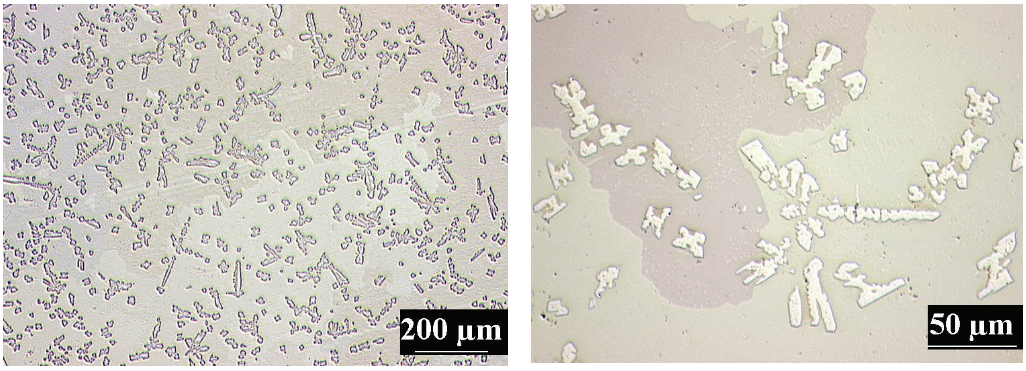


Fig. 1 Bi – Ag binary diagram

The production of the BiAg11 solder was started with the production of the alloy. In order to ensure the purity of the alloy, the casting process must be conducted under vacuum. A suitable casting process connected with an optimized temperature profile ensures a homogeneous distribution of silver in the metal casting thus manufactured. The solder was developed in VÚK Panenské Břežany, Czech Republic (Metal Research Institute, Ltd.). Subsequently, wire can be produced from the casting (by way of e.g. extrusion or drawing) while the alloy must be heated to 165 to 175 °C.

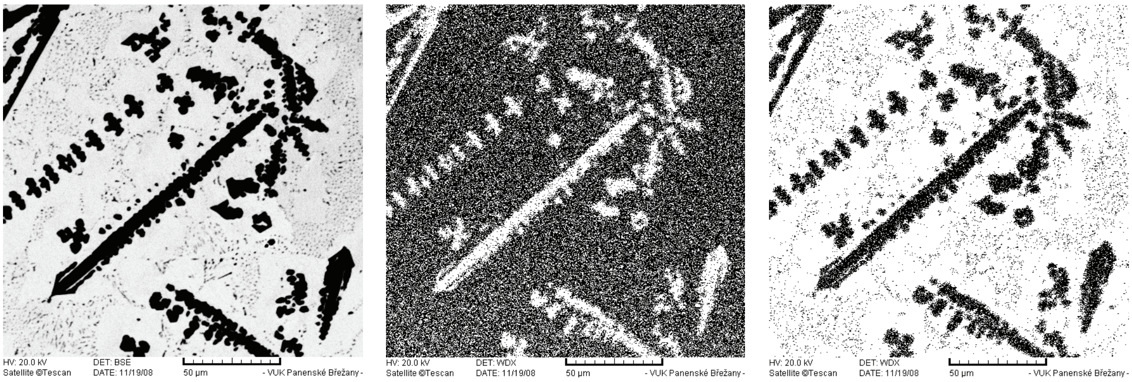
An optical microscopic analysis was conducted on the liquid solder thus produced, then a chemical microanalysis and a semi-quantitative chemical analysis [5].

Figure 2a shows the BiAg11 solder's micro structure. The basal phase (which is rich in Bi) contains small formations of the other phase (rich in Ag) generated relatively evenly. These formations are of multifarious shapes – from tiny equiaxed grains to longer acicular particles or even branched stars. In Figure 2b, there are boundaries between relatively large grains finely marked in the basal phase; the grains are shown in the state after casting.



a) *b)*

Fig. 2 BiAg11 solder microstructure



BSE *x-ray Bi* *x-ray Ag*

Fig. 3 Planar chemical microanalysis of BiAg11 solder

The chemical microanalysis was conducted on the surface of a metallographic cross-section. The results are documented in Fig. 3. The first photograph was taken in the backscattered electrons (BSE) mode. The rest of the pictures in Fig. 3 have been obtained from X-ray radiation of the Bi and Ag elements.

The comparison of the three photos implies that the basal matrix of the materials is made up of bismuth with a small percentage of silver – this is a very fine eutectic. Inside the matrix, variously shaped particles are distributed consisting primarily of silver. Immediate surrounding of these particles is depleted of silver, so these portions are mostly made up of bismuth.

The semi-quantitative chemical analysis was conducted on the solder's basal matrix, inside the particles contained in the matrix and in the immediate surrounding of these particles. The following findings were made based on the above-mentioned measurements:

- Dark particles are primarily crystals formed from the material containing approximately 95 % Ag and 5 % Bi.
- The immediate surrounding of the particles consists of virtually pure bismuth (while the Ag content is 0,1 – 0,2 %, at the most).
- The basal matrix is a very fine eutectic containing approximately 3 to 4 % Ag, the rest bismuth.

3 BIAG11 SOLDER WETTABILITY MEASUREMENT

Samples with dimensions of 40 x 40 x 0,5 mm were used to test the wettability of the BiAg11 solder. On a clean and degreases area in the middle of the sample 1gramm of BiAg11 solder was laid and 0.5 gram of 3.1.1.A-type addition agent. The testing soldering temperature was set at 380 °C.

After the wettability tests were completed, metallographic cross-sections were prepared with the aim to identify contact angles of wetting and conduct observations at the interface between the basal material and solder.

The results of the BiAg11 solder wettability testing are documented in Figures 4, 5, and 6. The best wettability was achieved for the silver sample. The wetting angle was 17°, which can be considered a very good wettability. For the copper sample, the wetting angle was 43°, which can be considered a good wettability. The worse wettability was detected for the nickel sample where the wetting angle measured was 70°.

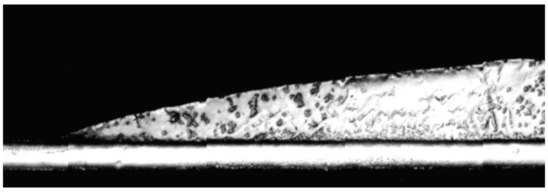


Fig. 4 Sample of BiAg11 solder wettability on silver, with a wetting angle of 17°

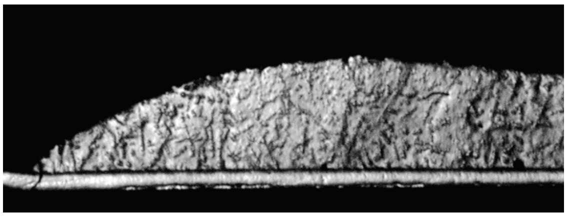


Fig. 5 Sample of BiAg11 solder wettability on copper, with a wetting angle of 43°

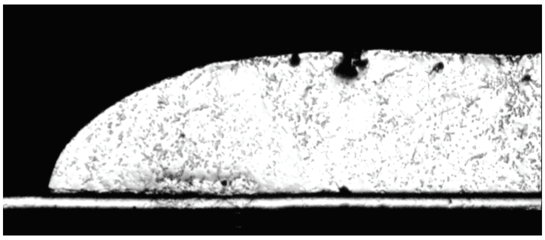


Fig. 6 Sample of BiAg11 solder wettability on nickel, with a wetting angle of 70°

4 CONCLUSIONS

The objective of the experiments performed was the production and assessment of lead-free solder as an alternative to the existing SnPb95 solder with a high lead content that has been granted a legal exception since there is no adequate replacement for it, for the time being.

After applying the criteria for selecting a type of solder for higher application temperatures, the Bi89Ag11 solder was proposed as a reasonable replacement.

The proposed solder was produced in the as-cast state. In order to ensure the purity of the alloy, the casting process was conducted under vacuum. A suitable casting process connected with an optimized temperature profile ensures a homogeneous distribution of silver in the metal casting thus manufactured.

The BiAg11 solder produced under this study has a melting temperature of approx. 262 °C through 360 °C. The soldering temperature is proposed at 380 °C.

The analyses completed imply that the basal solder matrix is made up of bismuth with a small percentage of silver. Inside the matrix, variously shaped particles are distributed that are rich in silver. The solder's structure is made up of fine eutectic.

The wettability tests completed for the designed BiAg11 solder determined that the best wettability was achieved for the silver sample. The wetting angle on silver surface was 17°, which can be considered a very good wettability. For the copper sample, the wetting angle was 43°, which can be considered a good wettability. The worse wettability was detected for the nickel sample where the wetting angle measured was 70°.

The designed/proposed BiAg11 lead-free solder, the application of which represents an increase in costs, is the only solder type with melting temperature (260 °C) similar to that of high-lead solders. Moreover, its price is substantially lower than that of gold-based solders proposed so far (such as AuSn20, Au12Ge, Au2Si etc.).

Credits and Acknowledgments

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