MINING AND METALLURGY INSTITUTE BOR
and
TECHNICAL FACULTY IN BOR, UNIVERSITY OF BELGRADE

IOC2026

International October Conference

57th International October Conference
on Mining and Metallurgy

PROCEEDINGS

Editor:
Ana Kostov

05 - 07 October 2026
Bor Lake, Serbia

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THE INVESTIGATION OF THERMAL PROPERTIES AND MELTING BEHAVIOUR OF Sn78Bi22 SOLDER ALLOY

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Abstract

In the present study, the Sn78Bi22 alloy was investigated as a potential solder material. The study focused on the evaluation of thermal diffusivity and thermal conductivity over a defined temperature range, differential scanning calorimetry (DSC) analysis, and an assessment of soldering behavior through measurements of contact angle, spreading area, spreading ratio, and intermetallic compound (IMC) layer thickness. The investigated alloy exhibited reduced thermal diffusivity and thermal conductivity compared with literature data for pure Sn. DSC analysis indicated a decrease in melting temperature compared with pure Sn reported in the literature, resulting from the addition of Bi. Soldering behavior was evaluated as favorable, characterized by a thin IMC layer, a low contact angle on a Cu substrate, and high spreading ratio and spreading area. Based on these results, the Sn78Bi22 alloy shows potential for lead-free soldering applications.

***Keywords**: Sn78Bi22, DSC analysis, thermal properties, soldering behavior*

1. INTRODUCTION

Solder materials play a crucial role in the reliable joining of circuit boards, electrical contacts, photonic circuits, and other electronic components [1,2]. For many years, Sn–Pb alloys were widely used as standard solder materials. However, due to strict regulations imposed as a result of lead toxicity, Sn–Pb solders are increasingly being replaced by alternative Sn-based solder systems, including Sn–Bi alloys [3,4]. To satisfy the requirements of modern electronic applications, solder materials must exhibit adequate thermal and mechanical reliability [5]. In addition, solders are required to possess a relatively low melting temperature (typically around 200 °C), good wettability and spreadability, and low susceptibility to excessive intermetallic compound (IMC) formation, which can adversely affect joint reliability by promoting brittleness [2,5]. Consequently, the identification of new solder compositions and the systematic investigation of their properties remain an ongoing challenge for researchers.

2. EXPERIMENTAL

2.1. Sn78Bi22 synthesis

High-purity tin (99.9 wt.%) and bismuth (99.9 wt.%) were used as starting materials for the synthesis of the Sn78Bi22 alloy. The constituent elements, in granular form, were charged into a graphite crucible and heated to 350 °C in a muffle furnace

until complete melting was achieved. To limit oxidation during the melting process, the crucible was protected with a carbon cover. The liquid alloy was then subjected to mechanical agitation using a graphite stirrer to achieve uniform compositional mixing.

Following homogenization in the liquid state, the melt was poured into a cylindrical steel mold with a diameter of 13 mm. The solidified specimens were subsequently subjected to a homogenization heat treatment at 150 °C for 20 h in an electric furnace in order to improve the distribution of Bi within the Sn-rich matrix, after which they were allowed to cool in air.

2.2. Determination of the thermal properties

The thermal diffusivity and specific heat capacity of the alloy were evaluated using the light flash method in the temperature range of 25–100 °C with a TA Instruments DXF-500 apparatus. The thermal conductivity was subsequently determined by multiplying the measured thermal diffusivity, specific heat capacity, and density values.

2.3. Investigation of the melting behavior

The melting characteristics of the alloy were examined by differential scanning calorimetry using a TA Instruments SDT Q600 system. Specimens with an average mass of about 20 mg were subjected to heating from ambient temperature up to 300 °C at a constant rate of 10 °C·min^{-1} in a nitrogen-controlled atmosphere.

2.4. Investigation of the soldering characteristics

Soldering behavior was assessed through the evaluation of wetting angle, spreading area, spreading ratio, and intermetallic compound (IMC) layer thickness. Reflow experiments were conducted on mirror polished Cu substrates (20 × 20 × 0.5 mm). Cylindrical solder sample (2 mm × 2 mm) was placed on the substrate together with the RMA 218 flux and reflowed on a hot plate at 250 ± 5 °C. After reflowing, residual flux was removed with acetone.

The spreading area was determined from digital images of the reflowed solder using ImageJ software, while the spreading ratio (SR) was calculated using Eq. 1. For contact angle and IMC thickness measurements, soldered joints were cross-sectioned, mounted, metallographically prepared, and examined using Carl Zeiss Jena Epytip 2 and Reichert MeF2 optical microscopes, with quantitative analysis performed using ImageJ.

$$SR(\%) = \frac{D-H}{D} \times 100 \quad (1)$$

3. RESULTS AND DISCUSSION

3.1. Thermal properties

Figure 1 presents the variation of thermal diffusivity and thermal conductivity with temperature. The thermal diffusivity of pure tin at room temperature is approximately 40 mm^2·s^{-1} [6]. In this study, the Sn78Bi22 alloy exhibited a thermal diffusivity of 26.7 mm^2·s^{-1}, corresponding to a ~33% reduction. The calculated thermal conductivity at room temperature was 45.15 W·m^{-1}·K^{-1}, representing a ~32% decrease relative to pure tin (66.6 W·m^{-1}·K^{-1}) [7]. In metallic systems, thermal transport occurs mainly through the motion of free electrons and lattice vibrations (phonons), with the measured thermal diffusivity and

conductivity representing the combined effects of these mechanisms. Since bismuth has a much lower inherent thermal conductivity than tin [7], its addition to the Sn matrix results in the formation of Bi-rich regions that are less effective at carrying heat. Furthermore, Bi-rich particles at grain boundaries promote grain refinement, decreasing the average grain size and increasing the total grain boundary length. As a result, the density of electron scattering centers rises, effectively impeding electron transport and reducing both thermal diffusivity and thermal conductivity [5,8].

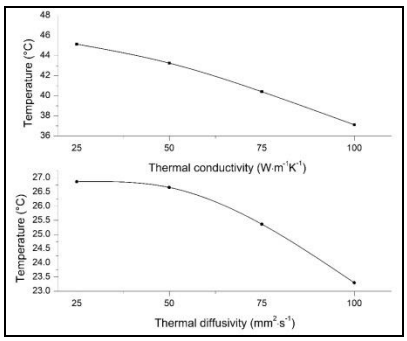


Figure 1. *Variation of thermal diffusivity and thermal conductivity as a function of temperature*

3.2. Melting behaviour

The melting temperature is a critical characteristic of solder materials, as a sufficiently low melting point—preferably below 250°C—is required to minimize the risk of thermal damage to adjacent electronic components and to ensure a narrow melting interval [5,9]. Figure 2 presents the DSC thermogram of the Sn78Bi22 alloy. Analysis of the curve indicates a melting peak at 211.6°C, with a melting interval of 29.6°C, defined by an onset temperature of 198.4°C and an offset temperature of 228°C. An additional thermal event observed at approximately 141 °C corresponds to the eutectic reaction, which occurs at 138°C according to the Sn–Bi phase diagram [4].

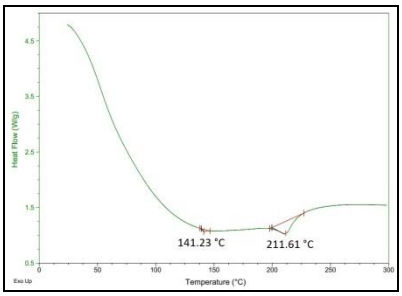


Figure 2. *DSC heating curve for Sn78Bi22 alloy*

3.3. Soldering behavior

Soldering performance is a key factor in electronic manufacturing, as the formation quality and durability of the joint between the solder and the substrate depend on both the intrinsic characteristics of the solder material and the applied soldering conditions. This performance is commonly evaluated through parameters such as contact angle, spreading area, and the thickness of the intermetallic compound (IMC) layer, and in some cases by the

spreading ratio [1,2,10]. The results of the soldering behavior evaluation are summarized in Table 1. Based on these indicators, the soldering characteristics of the investigated alloy can be classified as good to moderate.

Table 1. *Results of the solder behavior testing*

Sample	Contact angle (°)	Spreading area (mm^2)	Spreading ratio (%)	IMC layer thickness (μm)
Sn78Bi22	23.2	25.5	79.23	2.02

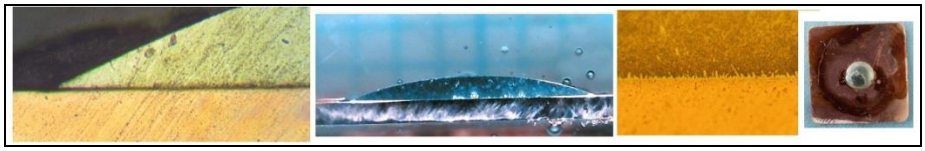


Figure 3. *Characterization of contact angle, intermetallic compound (IMC) layer, and spreading behavior of the Sn78Bi22 solder on a Cu substrate*

4. CONCLUSION

Based on the presented results, the Sn78Bi22 alloy exhibits a reduced melting temperature, decreased thermal diffusivity and thermal conductivity compared with pure Sn, while demonstrating favorable soldering behavior characterized by low contact angle, good spreading, and a thin IMC layer on a Cu substrate. These properties indicate that the addition of Bi effectively modifies both thermal and soldering characteristics without compromising joint formation. Overall, the Sn78Bi22 alloy can be considered a promising candidate for lead-free soldering applications requiring controlled melting behavior and reliable interfacial performance.

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